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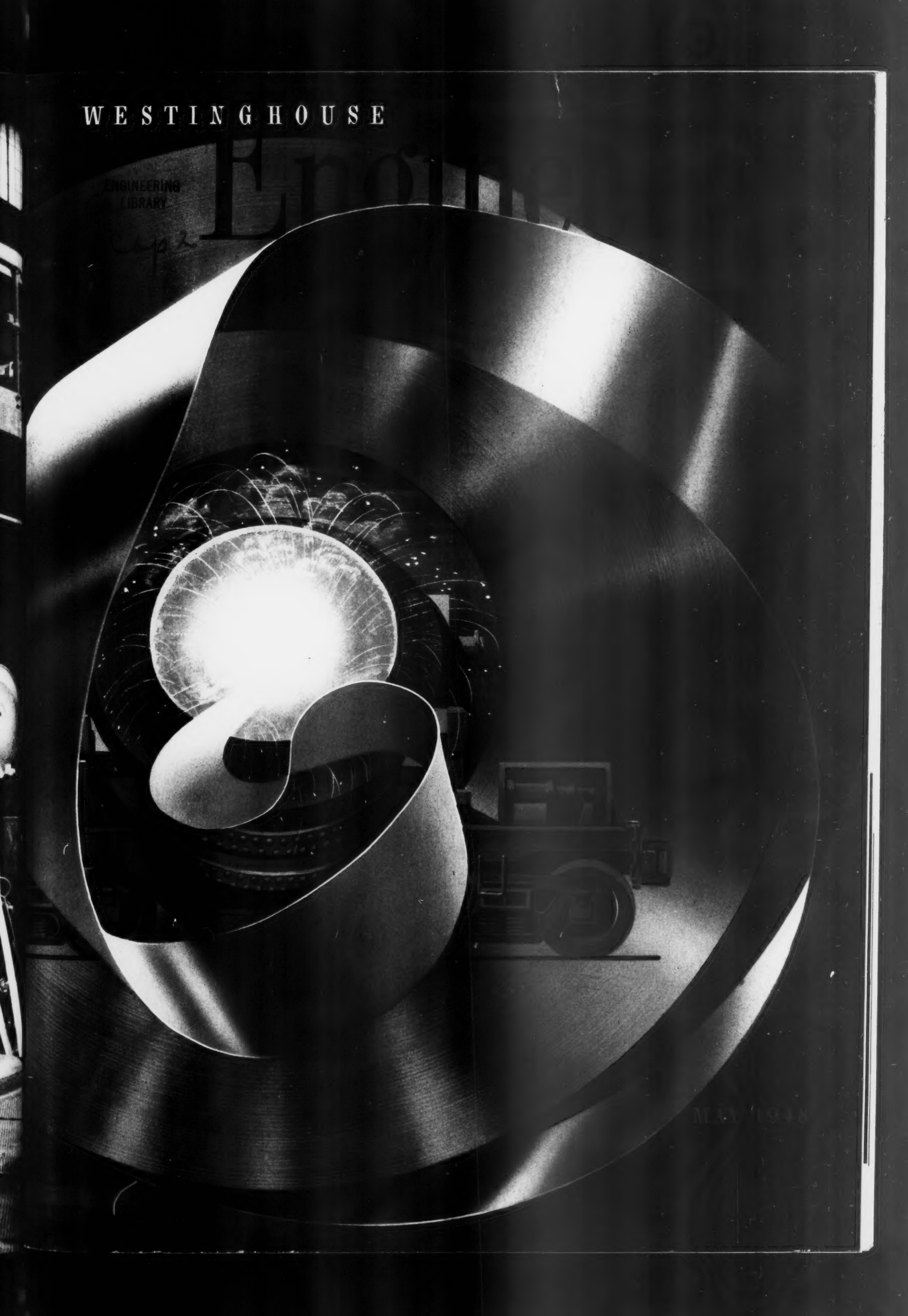

The Power Capacitor—LITTLE BOX, BIG JOB

After a slow start, the power capacitor has become a major component among electrical equipments. Capacitors are now being applied to power systems at the rate of one and a quarter million kva per year. About ten million kva are now in service in the United States.

The curve of use of power capacitors resembles the path of a jet-propelled fighter plane gaining altitude. Thirty years ago there were only trial or experimental installations in service; twenty years ago, a meager 300 000 kva had been added to lines; only ten years ago the figure had not yet reached a million and a half.

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Use of shunt capacitors to correct power factor began in a tentative, trial way as far back as 1912. But the failure rate was nothing to be proud of on the early units, which were made pretty much on a laboratory basis. In 1924 Westinghouse built a factory just to manufacture capacitors, and quantity production with appropriate quality controls began.

Power companies started to use capacitors only recently. Until about 1936 they were usually applied by consumers of power, the decision being on the basis of savings in power bills. In 1936 Westinghouse brought out the first outdoor or weatherproof capacitor with sealed case and solder-sealed terminals —a unit that could be mounted in the open, on a pole perhaps, without the cost and bulk of protective housings. Since then the use of capacitors by power companies has grown steadily.

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Installations of power capacitors have become sizable. One power system has in a fairly concentrated installation over 100 000 kva of capacitors. The largest industrial installation is about 50 000 kva. Blocks of 10 000, 20 000, and even 30 000 kva are fairly common.

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Behind the steadily rising use of power capacitors is, of course, the declining bulk and cost per kva. Two decades ago they weighed about ten pounds per kva. This figure declined continuously with the 15-kva units, standard until recently, until it stood at about 3.3 pounds per kva. With the new 25-kva unit, the figure drops to below three pounds.

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Several factors have led to the steady improvement in capacitors. The switch in impregnating liquid from oil to non-inflammable chlorinated hydrocarbons of the Inerteen type brought a sharp reduction in size. This is because of its much better dielectric constant. Another feature is non-inflammability, which makes it possible to install capacitors in the open in industrial plants. This eliminates the necessity of a vault-type enclosure, thereby reducing installation cost.

The improvement in impregnant came all at once. The improvement in paper has come by degrees. The problem has been to produce a paper completely free from conducting particles, with low electrical losses, and without ionic components that are leeched out of the paper by the liquid. Production of capacitor paper has become a highly developed specialty. It is made from carefully selected wood, such as hemlock, and processed with utmost care to produce as a paper that is as pure cellulose as possible. It is also one of the thinnest papers made—0.00035 inch.

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The metal foil used today is quite different from that of 25 years ago. Then it was "tin foil" (85 percent lead, 15 percent tin) one-half mil thick. Soon aluminum fabricators were able to provide aluminum foil of the same thickness, giving an approximately four to one saving in weight. The thickness has been reduced at intervals, so that now the aluminum foil used is but one-quarter mil thick. This represents an eightfold saving in foil weight since the first commercial capacitors.

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A most important factor in capacitor manufacture is the extreme care with which every step must be performed. This has brought about a host of rigid processes and quality controls difficult to evaluate specifically but without which the modern capacitor would be impossible.

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Power capacitors have many uses. Most common and best known is to correct power factor and improve voltage regulation of 60-cycle power-distribution systems. They are also used for energy storage in resistance welders, surge generators, and airport-runway indicators. They are used as high-frequency filters, as tuning units, and to discriminate between frequencies. Used in series instead of shunt they compensate for power-line reactance during rapid load changes. Series capacitors are used with resistance welders to compensate for reactance and thus reduce the kva inrush peaks. Power capacitors are an unquestioned must with high-frequency generators. For example, a 4500-kva, 5000-cycle induction furnace is served by a 100-kw generator. Without the 4500-kva capacitor the high-frequency generator would have to be designed for 4500 kva.

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The power capacitor, compact, silent, and motionless, is figuring more prominently in modern electric-power systems. It is a reliable, efficient power device. While it has changed little in appearance in a quarter of a century, except in size, it embodies almost as much research and development as any major electrical equipment.

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On the Side

The Cover—by Dick Marsh. Raw, molten iron from the blast furnace, passed through a series of processing operations, becomes the finished products of a thousand and one uses—strip and sheet steel.

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The large measure of success attained on tests of the experimental 2000-hp, locomotive-type gas turbine at South Philadelphia has led to the decision to build a two-unit locomotive. The two turbines will differ from the test unit only in minor improvements. Sitting side by side and complete with d-c generators, the gas turbines will provide a 4000-hp locomotive in less than thirty feet of length. The modern "iron horse" is expected to be about two thirds the weight and one half the length of a similarly rated diesel-electric. Furthermore, the locomotive will have no reciprocating parts, thus minimizing vibration, will require little lubricating oil and no water- or ash-handling facilities, and will be capable of operating on almost any type of liquid fuel.

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Recent graduates in engineering are finding more and more that their education is really just beginning. A seven-month postgraduate course conducted by Westinghouse in cooperation with utilities for young central-station engineers was inaugurated last fall. It has proved to be so successful that the course will be repeated starting in September, 1948. Operated in similar fashion to that conducted for the Company's own student engineers, the course covers shop training and theory on such topics as electrical transmission, distribution, and generation equipment and power-plant operations.

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Two blast furnaces each with its quartet of stoves make a scene characteristic of steelmaking. It is here that iron in ore is reduced to pig iron.

Steel

How Made and How Much

Like a robin trying to fill the cavernous upturned mouths of her brood with no seeming success, the steel industry has turned out in 1947 a total of 85 million tons of steel, 32 million tons more than in 1939—but it hears only the words, "more, more." To evaluate the job done and what the future of this basic industry may be like requires a review of the complex business of steelmaking and the many factors, technical and social, that will influence its performance.

IF OIL is the life blood of the nation, certainly steel is its bone structure. Both are now conspicuous in the news—usually being mentioned in the same breath with "scarcity." Steel, like oil, is in short supply. This is in spite of the fact that the production of steel ingots last year totaled 84.7 million tons, which is only 5 million short of the wartime peak, and 32 million tons or 60 percent more than in 1939—the last reasonably normal year.

To estimate when supply will overtake demand, if at all, is more than we can achieve here. However, to evaluate the discussions in the trade and news press requires consideration of many things: prewar and existing steelmaking capacities and productions, shifts in types of steel demand, new plant expansions, iron ore and coke availability, the extremely critical scrap situation, use of oxygen, strikes, aid to Europe, synthetic-fuel program, and numerous other pertinent factors. The necessary backdrop for this picture is an understanding as to what constitutes the complex process of steelmaking.

How Steel Is Made

Production of a ton of steel is, to the layman, an astonishingly long chain of events, each link essential to the next. It begins, of course, with mining. Four main substances are required to make a ton of pig iron, which is subsequently refined to make steel: 1.73 tons of iron ore, 0.93 ton of coke, 0.41 ton of limestone, some cinder scale and scrap, and 4.5 tons of air. The air, thank goodness, is relatively free and truly inexhaustible. Limestone (or dolomite) is cheap and abundant, and by comparison with ore and coke it offers few problems.

To make a ton of coke requires about 2850 pounds of Pennsylvania coal. Coals suitable for coking (a very small percentage of the United States total) are located mostly in Pennsylvania, West Virginia, Kentucky, and Alabama. While the total amount is large and ample for many years, the quality is declining. In fact the new coking coal mines being opened now in the Pittsburgh area are higher in ash and sulphur content, which reduces the output of the blast furnace.

Most coke is now made in by-product coke ovens. The picturesque and colorful beehive ovens, popular until a decade or two ago, are obsolete and declining in use because they waste the many valuable volatile coal chemicals. Now nearly every steel plant has a battery of coke ovens whose capacity is integrated with its iron-making abilities. An essential fact to remember is the equal importance of coal and iron ore. Nearly as much coal is needed as ore but it is only one fourth as bulky to transport. The location of the steel mills is no accident.

The iron-ore situation is a whole subject in itself.* Suffice it to say that 80 percent of the iron made in the United States is from ores mined in the iron ranges of Minnesota and converted to steel in mills on or near Lake Michigan and Lake Erie. The mills in Alabama, Utah, Maryland, and other areas are important but small in aggregate product as compared with the present major production centers. Except for the Baltimore mills, which convert South American ores, they live principally by local ore mined underground.

The Blast Furnace

After the ore, coke, limestone, and numerous alloying materials are collected, the first major process is to reduce the iron ore (which in the United States is always one or more of the iron oxides) to pig iron. This is done in the blast furnace.

The blast furnace is a huge, vertical, cylindrical structure of steel standing perhaps 100 feet high and 25 feet in diameter, and lined with refractory brick. Carefully measured quantities of iron ore, coke, and limestone are carried up an incline by a skip car and dumped into the top of the furnace, so that it is

Prepared by Charles A. Scarlott based on information and assistance provided by the staffs of Westinghouse, American Iron & Steel Institute, the "Iron and Steel Engineer," the U. S. Steel Corporation, Bethlehem Steel Company, the Automobile Manufacturers' Association, the U. S. Department of Commerce, and the President's Board of Economic Advisors.

*"Iron Ore Reserves of the Nation," Westinghouse ENGINEER, July, 1945, p. 110.

kept nearly full. Hot air from adjoining stoves, fired by waste gases from the furnace, is introduced through tuyeres near the bottom. The coke burns and forms carbon monoxide which, in turn, reduces the iron oxides in the ore, leaving the iron in the metallic liquid state. It trickles down through the charge and collects in a pool at the bottom of the furnace. At the same time the limestone is calcined by the heat of the furnace. The resulting lime combines with part of the impurities in the ore and coke forming a molten slag, which floats on the iron.

Slag is drawn from the furnace at frequent intervals, while the iron is tapped four to five times a day in "casts" ranging from 150 to 300 tons, according to the size of the furnace. The average daily production is about 1000 tons of pig iron.

The blast furnace operates continuously, week after week, sometimes for years, until repairs are necessary or its product is not needed—which has not been recently.

The product of the blast furnace is pig iron, poured as a liquid either into ladles, or transported by hot-metal cars for delivery direct to subsequent steelmaking processes. A small percentage is made into molds, called "pigs," of about 80 pounds each. The term "pig" comes from the one-time practice of casting the iron in molds resembling suckling pigs.

Pig iron is high in carbon, usually from 4 to 4½ percent, because in the blast furnace the molten iron absorbs carbon from the burning fuel. Also it contains all of the phosphorus and much of the silicon, manganese, and sulphur in the original ore. To obtain steel nearly all of these impurities must be eliminated. This refining is done in one of three types of furnaces: bessemer, open-hearth, or electric.

The Bessemer Converter

The bessemer is the oldest of the three types. It carries the name of Henry Bessemer, who patented it in England in 1851, although it was later substantiated that an American, William Kelly, had proved the idea five years earlier. The invention of the converter ushered in mass production of steel.

The bessemer is the enormous pear-shaped vessel belching great gusts of flame that characteristically redden the night sky of a steel town. To begin the bessemer cycle, the great vessel is tipped horizontally and charged with 15 to 30 tons of molten pig iron, perhaps brought direct by hot-metal cars from the blast furnace. It is then turned upright and a strong blast of air is blown in through the bottom. At the temperature of the molten iron, 2400 to 2700 degrees F, the impurities burn. The silicon and manganese burn first, and finally the carbon; this burning sequence accounts for the brilliant color in the 30-foot flames in the 10 to 15 minutes required for a "blow." No addition of fuel is required; in fact the reaction is exothermic so that the temperature of the metal rises several hundred degrees. Near the end of the blow period any alloying agents required are added. The vessel is tilted again, the finished steel pouring into a ladle. The lighter slag overflows into a thimble for cartage to the dump.

The bessemer as practiced in this country is incapable of removing phosphorus, and special quality hot metal, low in phosphorus content must, therefore, be used in this process. Bessemer steel, while prized for wire, free-cutting steel, and welded pipe, accounted for less than six percent of the nation's 1947 total steel production.

The Open-Hearth Furnace

The high-tonnage producer of steel today is the open-hearth furnace, whose output last year comprised 91 percent of the total. This type of furnace is the invention of William and Frederich Siemens in England in 1856.

The hearth of a 200-ton furnace consists of a shallow "dish" about 50 feet long and 20 feet wide, under a low roof of refractory brick. The furnace is charged with molten or solid pig iron, scrap, and some iron ore and limestone. Preheated fuel, gas, oil, or tar, and air under pressure are introduced at one of the ends, or, in many cases, fuel oil atomized with steam is used. As the fuel burns above the charge the heat is reflected downward by the low ceiling, heating the charge to about 3000 degrees F where the impurities oxidize, much as in the bessemer. The hot gases pass out of the furnace at the far open end, and through openings in brickwork, called checkers, giving up some heat to the brick. After about 15 minutes' operation the direction of gas and air flow is reversed so that air and possibly the fuel are heated as they pass through the hot checkerwork and into the furnace, conserving heat.

Molten steel and slag are discharged at the rear of the furnace. The time for a complete heat varies from 9 to 15 hours, depending on furnace size and the kind and temperature of the charge. As much as 225 tons are produced in a single heat, the average, the country over being about 85 tons.

The basic open-hearth furnace is an extremely versatile, economical, high-tonnage producer. It can make a variety of steels from a variety of raw materials and can eliminate phosphorus, which the bessemer can't. It can be charged solely with scrap or with a high proportion of pig iron as price or availability of scrap dictates.

The Electric Furnace

The electric furnace is lowest of the three in tonnage, producing last year only four percent of the total. But because of the close control possible during its refining operation, this product constituted some of the highest grade alloy steels.

The arc furnace is a cylindrical chamber pivoted on the

Most spectacular, but becoming less important in the total of all steelmaking processes, is the bessemer converter. One furnace is midway in a "blow," a second is being charged with pig iron.

(This photo and the one on p. 66 by courtesy of U.S. Steel.)

sides. It is brick lined and three giant carbon electrodes penetrate the interior from above. The furnace is charged with scrap and sometimes small amounts of pig iron, and later with the alloying elements. When three-phase power is applied arcs form. The resulting heat first melts the charge followed by the refining and alloying processes.

The arc furnace, too, is spectacular in performance. The huge carbons glowing red where they enter the furnace, multicolored gases issuing through the electrode openings, the rumble of melting scrap, and the hum of the furnace transformer conspire to give a Dante's Inferno impression. Heats last from 4 to 7 hours, and the steel produced per heat varies up to 100 tons, 25 or 30 being average arc-furnace production.

From Ingots to Sheet or Strip

By any of the three routes we arrive at steel with a carbon content that may range up to a maximum of 1.7 percent and generally much less, low in impurities, but possibly containing certain alloying elements, depending on the final objective. Ingots produced for blooms, to be rolled into wire, structural steel, bars, etc., average two feet square and weigh five tons. Ingots rolled in large blooming mills or slabbing mills for flat products average about 2½ by 5 feet and weigh 20 tons.

The succeeding steps from ingot to finished product are essentially mechanical. They consist for the most part of successive forming between rolls to improve the quality of the steel and bring it to the desired shape, with heat treatment for metallurgical reasons at appropriate stages. Because of the great variety of finished products—battleship plates, rails, bridge and building beams, bars, rods, sheet, tin plate, wire, pipe, nails, down to paper clips and bobby pins—the number and sequence of forming and heat-treating operations greatly differ. Because of the insatiable demand at present for automobiles, refrigerators, washing machines, tin cans, and similar consumer goods, the production of steel sheet will be taken as illustrative of steel-processing operations.

The ingot spends several hours in a soaking pit so that its temperature is a uniform 2100-2300 degrees throughout. It is then ready for the first rolling operation, in a blooming or slabbing mill. Here it is passed through massive steel rolls, first in one direction, then in the other until it is squeezed from its original 2 by 2 feet to a slab of approximately 4 to 6 inches thick and 30 to 60 inches wide. The front and rear ends of the slab are trimmed in a shear to eliminate natural metallurgical defects, and the remainder cut into suitable furnace lengths. They are reheated to a rolling temperature of about 2300 degrees F and passed to the continuous hot-strip mill. This may consist of ten sets of roll stands, the first four being roughing stands and the last six finishing stands. The strip emerges from the last stand squeezed to 0.200 to 0.065 inch thick and 30 to 96 inches wide, depending on whether it is to be cold rolled for automobile bodies, refrigerator cases, or tin plate. The strip as it leaves the last stand is usually wound into a coil of several tons.

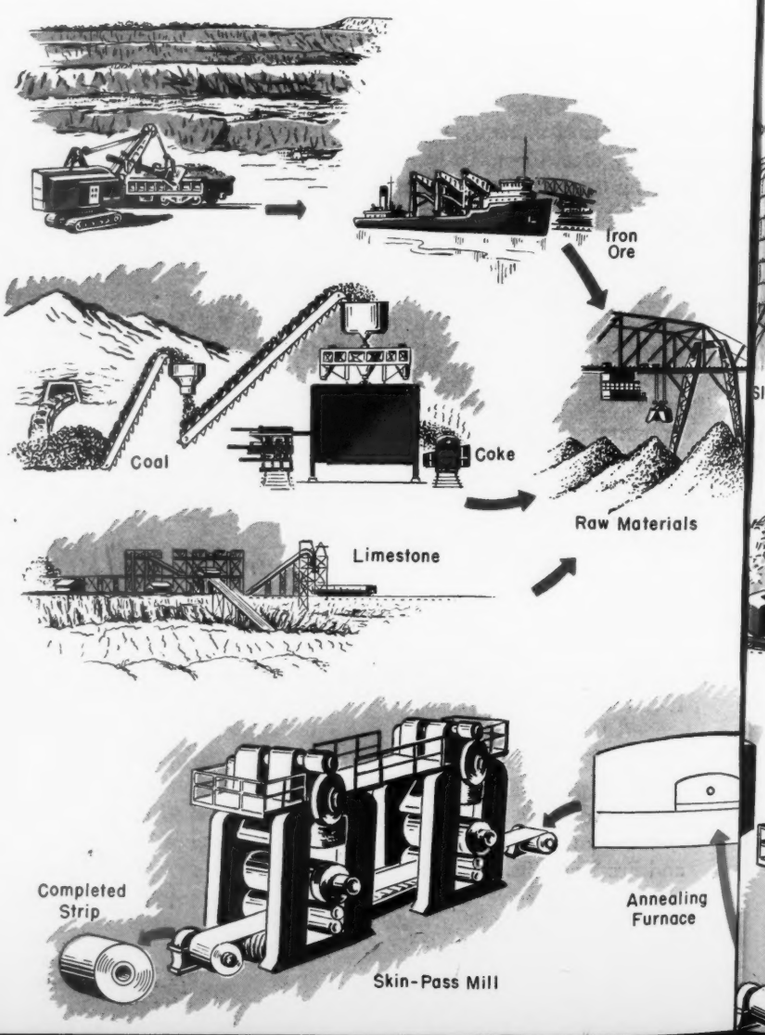
After the coil is cooled it is passed through a pickling line where it is cleaned, first with acid, then hot water, and finally oiled to inhibit corrosion while awaiting the cold-reduction mill. This is a three-, four- or five-stand mill that rolls the cold strip to the final desired thickness. The strip is recoiled and sent to the annealing furnace to remove the cold-work strains. The steel is now soft so it must be sent through a skin-pass or temper-pass mill that gives it no appreciable reduction but hardens it sufficiently for later forming operations. By stretching it slightly, its metallurgical properties are improved.

Status of the Steel Industry

The first solid observation that arises out of this brief description of steelmaking is that it is a long and complicated series of processes, each one involving enormous capital. Above all it is clear that to obtain, say, another million tons of sheet steel yearly for more automobiles, refrigerators, or tin cans, is not just a matter of building a new strip mill. Obviously, a new strip mill is useless unless it can be provided with slabs. And almost no spare blooming mill or slabbing mill capacity is now at hand.

Any extra steel is badly needed for pipe, for example. Possibly increased oil-transportation facilities may be as important in the national economy as consumer goods about which one hears much more.

Naturally, too, more blooming mills are useless unless ingots are available, and at present no ingots suitable for strip or sheet are piling up anywhere. That means more open hearths. And so on back along the chain—scrap, blast furnaces, coke ovens, coal, ore boats, and iron-ore mining capacity, not to mention dozens of auxiliary but essential facilities such as furnaces, soaking pits, storage space, handling equip-



ment, etc. It is not a question now of removing the bottleneck to steel production; bottlenecks exist all along the way. At present nearly every element in steelmaking is working at the maximum practical rate except for small amounts of bessemer and electric-furnace capacity.

What then is the picture and what is being done about it? To see where the industry is going will be facilitated by a glance at where it has been and is now.

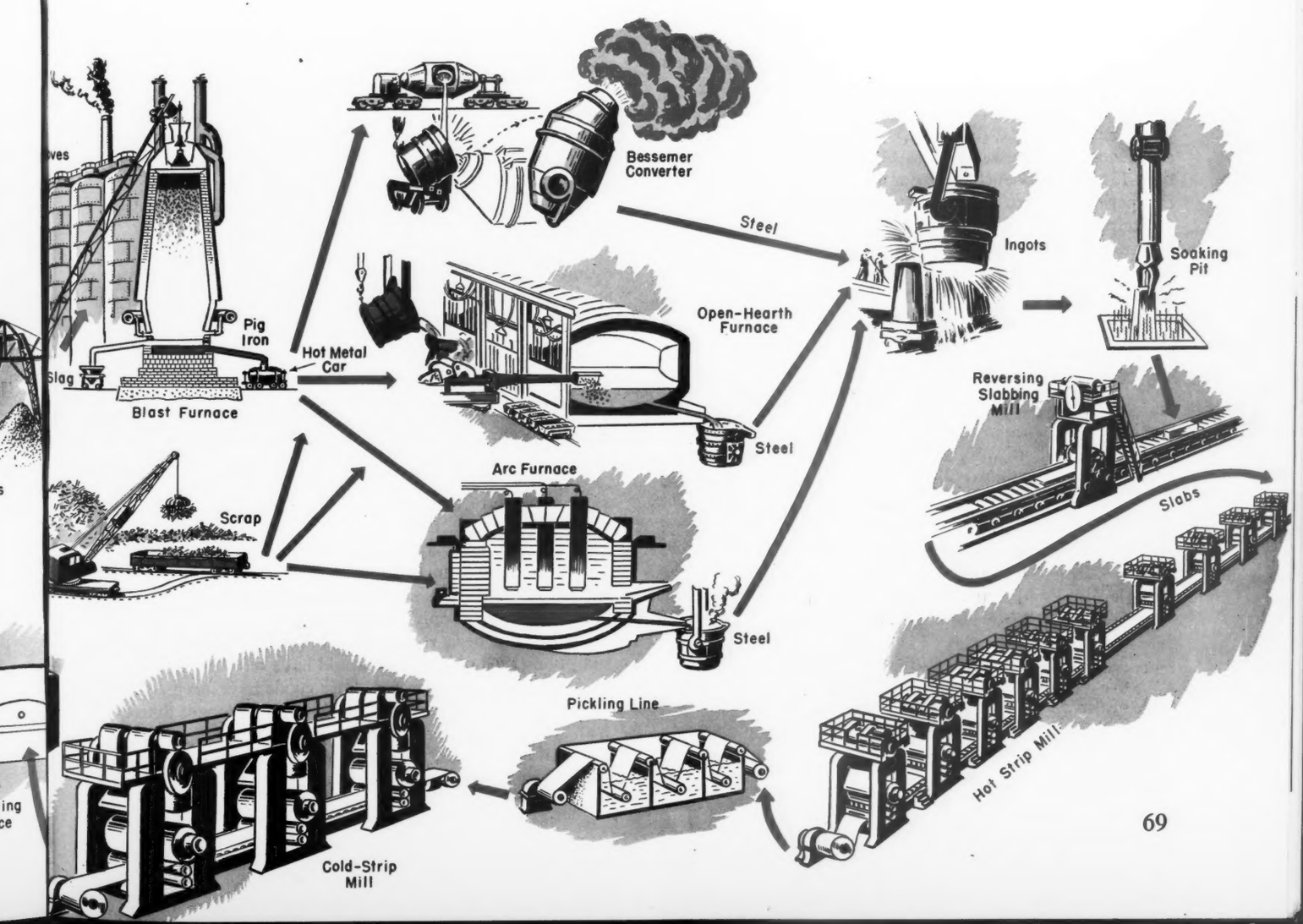
The History of Steel Capacity and Production

The record of steel capacity and actual production from 1910 to 1947 is given in Fig. 1. The capacity to produce steel ingots, from which finished goods can be made, grew from about 40 million tons per year in 1910 at a comparatively steady rate even during depression years, so that by 1938 it had just doubled, reaching 80.2 million tons that year. Under the pressure of war needs 15.3 million tons of additional ingot-making facilities were added, bringing the capacity to 95.5 million tons in 1945. The coming of peace, however, found some of the facilities worn out by the heavy war use, some long overdue for retirement and some uneconomical to operate in a peacetime economy. As a result the score at the beginning of 1947 stood at 91.2 million tons. Plans for new plants were well under way even by war's end. Some of these have been executed, more will be completed in another year. The ability to produce steel is expected by late 1949 to reach about 96.3 million tons.

The actual production of steel has, of course, followed a different and more irregular pattern than capacity. Between 1910 and 1929 it followed a zigzag course from about 30 million tons up to the boom peak of 63.2 million tons. Then came the depression. Steel shipments plummeted to 15.3 million tons in 1932 but by 1939 they had climbed from that cellar to 52.8 million tons, still roughly 10 million tons short of the 1929 peak. The war, of course, soon remedied that; an all-time record was set in 1944 at 89.6 million tons. The end of the war, with the many factors of reconversion, strikes, and tired equipment, brought a sharp drop in production—but not as much as nearly everyone anticipated—to 66.6 million tons in 1946. Since then production has steadily improved. In 1947 it totaled 85 million tons, which placed it only about 4.8 million tons under the all-time war-pressure peak, and 21.6 million tons (34 percent) greater than the peacetime peak in 1929. Also this is greater than the last reasonably normal year of 1939 by 32 million tons or approximately 60 percent.

Before 1940, when the oncoming war was beginning to be felt, the industry had never been called upon to make all the steel it could produce. This also is shown by Fig. 1. Production came within 90 percent of total capacity only twice—during World War I. After that it exceeded 80 percent only in 1926, 1928 and 1929. During the depression years it fell to 20 percent in 1932 and touched the peak of 73 percent in 1937. Even in 1939 with pre-war stimulated orders, but 66 percent of the steelmaking capacity was employed.

Members of the steel industry point with pardonable pride



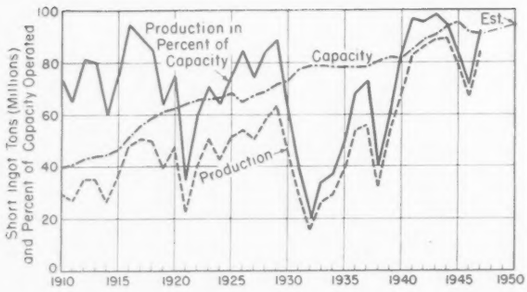


Fig. 1—The course of ingot capacity and ingot production in the United States. Also shown is capacity operated in percent of total installed.

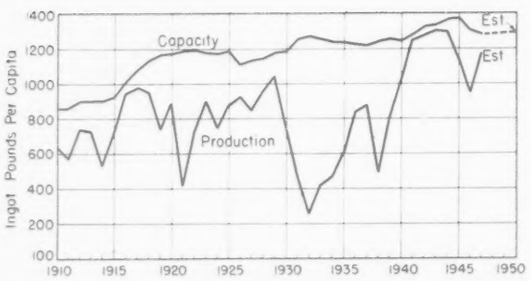


Fig. 2—On a per capita basis the capacity to produce steel ingots and the actual production have risen steadily.

to the relative growths of steel and population. These facts are summarized in Fig. 2. In 1910 the steel industry was equipped to produce about 850 pounds per capita and actually did produce about 650 pounds. In 1939, production capacity per person stood at 1250 pounds while actual production amounted to 800 pounds. The same pair of figures (ignoring export shipments) for 1947 are 1300 pounds and 1190 pounds. On a percentage growth basis population has risen 55 percent since 1910; steel capacity, 142 percent; steel consumption, 134 percent. Such increases are to be expected because this period has seen the mass production of the automobile, the refrigerator, the food can, and many other wholly new, steel-using consumer products.

These changes in demand are reflected in the types of steel required, as Fig. 3 indicates. The most conspicuous change has been in the steady rise—except during World War II—in demand for steel strip, sheet, and tin plate. This type of product averaged about 13 percent of the total in the 1915–1919 era. It rose to an average of 38 percent in the five prewar years, and stands now at around 36 percent of all steel produced. In specific amount the increase is even greater. Between 1915 and 1920, the average annual production of thin, flat-rolled steel was about 4 million tons; now it is over 22 million tons. Such are the demands of the American standards of living!

To assist in anticipating what steel production is likely to be and how well that production is likely to coincide with the country's near- and long-range needs, several participating elements can be set forth. In addition to the 3.5 million tons in new ingot-making facilities now scheduled (mostly open hearths) some other facilities are being added to maintain the integrated picture. These include: more blast furnaces to the tune of three to five million tons per year, most of which will be net increase; about three to five million tons of new coke-oven capacity; approximately three million tons of sheet and strip capacity; and some increases for other products such as

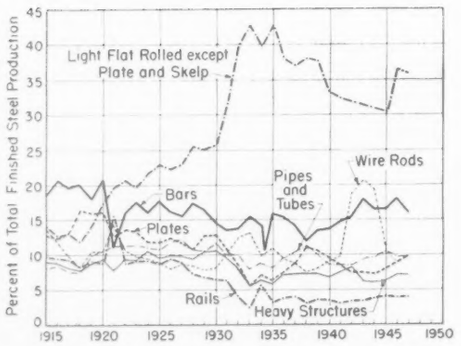


Fig. 3—The most conspicuous change in demand for steel has been the increase in use of sheet, strip, tin plate and other flat products.

pipe and wire. These additions, which will be substantially completed this year, represent an investment of well over a billion dollars, or about a third of the present total.

A sidelight to the picture of technical advances in the steel industry is the increased productivity of new plants as compared with the older equipments. Two cold-strip mills have gone into service within the last few months with maximum rolling speeds faster than a mile a minute. In 1940, the record stood at 2700 feet per minute; and in 1933, it was 500.

The Matter of Scrap

Some factors are operating to prevent steelmaking facilities from performing to their fullest. One is the matter of scrap, the importance of which is not sufficiently recognized outside the steel industry. Each ton of scrap available to the steelmaking furnaces reduces by 3½ tons the amount of other raw materials needed (iron ore, 1.7 tons; coal, 1½ tons; limestone and other, ½ ton). Not only does this spell an important saving in our natural resources but also means lighter equipment to meet the stepped-up ability of the furnaces to take the charge and produce refined steel.

The present scrap situation is extremely critical. It is estimated that had scrap been available in greater abundance last year another six million tons of ingots could have been produced. Steel men consider that a well-balanced open-hearth furnace operation requires almost as much scrap as pig iron. That has not been possible because scrap is scarce, and by the same token, costly. In fact the absurd phenomenon of a ton of scrap costing more than a ton of ingots has actually occurred; in 1947 scrap sold for $45 per ton when ingots brought $36. Furthermore, prospects for early improvement in quantity are not good.

Those close to the scrap situation summarize the scarcity as due to several factors. Some 20 million tons of scrap were exported, mostly to Japan, between 1930 and 1940. That was a horrible mistake in more ways than one. Also in fighting the war some 140 million tons of steel were shipped out of the country, of which only a tiny fraction will ever return. If this steel had been converted into products for home consumption much of it by now would have returned to the mills as scrap. Also, because consumer goods have been in short supply many have been continued in service longer than normal, with an additional drying-up effect on scrap available. For various reasons, some 150 to 160 million tons of scrap have been drained from the national reservoir, or roughly

enough for four years' operation at the present rate. This is but one way in which civilization pays for its war sprees.

Coal Quality

Quality of coal has a measurable effect on steel production. While stocks of high-volatile coking coals are available in ample quantities, the quality is declining. The ash content of coking coals now being used has risen from eight to nine percent in prewar years to about 12 percent in 1947. In addition the greater use of machine mining has introduced more slate into the coal, which in turn has required additional facilities for cleaning and washing. The higher ash and lower carbon content has increased coke consumption per ton of pig iron from approximately 1760 pounds in 1939 to 1868 pounds in 1946. Some operators say the productivity of their blast furnaces has declined ten percent on this account.

Use of Oxygen

Counterbalancing the factors tending to reduce steel production from available facilities are others that it is hoped will raise it. One is the use of oxygen. Commercial oxygen is used in the manufacture of open-hearth steel in two distinctly different ways. One is to enrich the open-hearth flame to hasten melt-down perhaps by as much as 30 percent, because the oxygen-enriched flame is about 500 degrees hotter than the conventional air flame and so reduces solid scrap and limestone to liquid metal and slag very rapidly. Flame temperature reached in ordinary open-hearth practice is about 3300 degrees F while temperatures of 500 degrees F higher, or more, are attained with oxygen.

Some operators have reported reduction in melt-down time by as much as 30 percent of normal practice time, a fact which may make necessary redesign of furnaces and charging equipment to meet the stepped-up ability of the furnaces to take the charge and produce refined steel.

The second use of oxygen in open-hearth steelmaking involves bubbling the oxygen into the molten bath and so hastening the rate at which carbon and other impurities are removed from the liquid metal.

The saving in time in this operation is not as great as in the melt-down period but savings of 17 to 30 percent have been reported. When oxygen is used directly in the bath it is not necessary to use as much iron ore to promote chemical reaction, an important item for the future consideration of the growing scarcity of domestic ore of open-hearth grade.

When the two different ways of using commercially pure oxygen are combined in one furnace, the saving in time becomes of prime importance because the daily capacity of the furnace to produce is so materially increased. For each one percent increase in the ingot operating rate, 650 000 tons of finished steel become available for consumer use. In addition to fuel and limestone saved, there is an increase of furnace yield of one or two percent, which is significant in times of high production of steel.

Many things must be done, however, before any such technical advance can be placed in general use. For one, more oxygen-producing facilities will be required. Also several yet unsolved technical problems attend the use of oxygen in existing furnaces, if maintenance is to be kept reasonable.

Higher Blast-Furnace Pressure

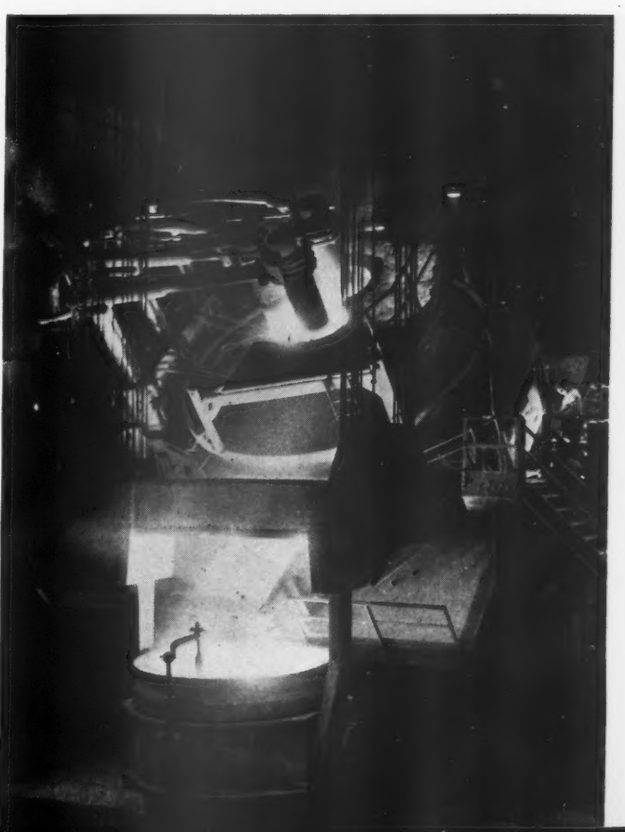
Another technical advance is the use of higher air pressures in blast furnaces. By adaptation, a blast-furnace outlet can be partially throttled to operate under pressure substantially above normal, with an increase in its output and reduction in coke consumption for each ton of pig iron produced. With the furnace throttled for pressure operation, it has been possible to increase the rate at which the blast is blown into one furnace from 75 000 to 100 000 cubic feet of free air per minute. Despite this high blast, the amount of flue dust normally blown out of the furnace is substantially reduced, because the velocity of the gases through the furnace is less at the higher pressures. With this increased blast input, more coke can be burned and more pig iron produced each day. At the same time, coke consumption per ton of pig is reduced. As the best supplies of coking coal become depleted and the necessity for increased use of lower grade cokes from which impurities must be removed becomes apparent, reduced coke consumption becomes increasingly important.

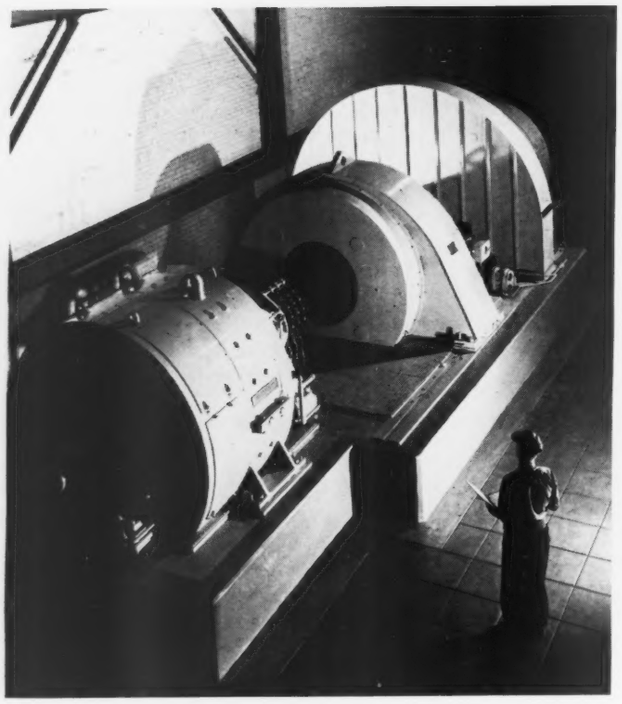
The Future Demand for Steel

The net effect of all these factors, assuming no major difficulties, is likely to spell a greater production of steel in 1948 than in 1947. Production is continuing to rise. But it is almost equally certain that this production will not equal the amount the fabricating industries would take.

What the eventual leveled-off, normal (if there be such a thing) demand will be is obviously known for certain by no one. Simply to extrapolate curves of past capacities, productions, consumption per capita, etc., while helpful, is hazardous. Slight deviations mean big differences in estimated totals. There are opinions, and naturally they don't agree. Steel-company leaders are rightfully proud of the industry's record and their programs for expansion. They point to the fact that if the prewar peak demands of all major steel-consuming industries—which did not always coincide, naturally—were totaled the figure would be about 50 million tons of finished steel. Actually 62 million tons of finished steel (not ingots) were made in 1947. This is a forceful argument that the industry can meet future "normal" high demands.

High-grade alloy steels are produced in electric furnaces such as this 70-ton unit of the Carnegie-Illinois Steel Corporation.





Electricity is a big factor in steel production. This is a motor-generator set supplying power to mill motors in a plant of the Allan Wood Steel Co., near Philadelphia.

Ingots are rolled to slabs in mills like this at Republic Steel Corporation. Slabs, rolled to thin gauges in hot mills, finally emerge as coiled strip from cold mills, such as this modern mile-a-minute mill at Weirton Steel Co., Weirton, W. Va.

The industry is also mindful that before 1940 the demand had but twice come closer than 90 percent to capacity, and generally has been less. Nor has it forgotten that in 1939 it was publicly investigated by legislative bodies on the charge of being overexpanded. Also a brake to further large-scale expansion is the present cost of new plants, probably double or triple that of plants built before the war. Steel men point to the figure of 18 million tons of production lost through work stoppages and say that would go a long way toward filling the gap between supply and demand. It should be remembered furthermore that it takes steel to make steel. Who is ready to step up and say with finality that it is better in the overall national economy to divert steel from product use to build more steel plants than to produce the maximum now possible for needed goods and add steelmaking capacity later, if and as needed? These are matters not answerable here.

It cannot be denied, however, that the need for steel will be great for years to come. There is evidence, for example, that although the curves of consumption per capita rose during the prewar years, they do not present a true picture of desire for goods made of steel. Possibly not all of the latent demand for steel created during the depression years was satisfied before the war cut off the consumer-goods supply almost entirely. It is difficult to say at what rate our standard of living, of which demand for steel products is a part, is actually rising. It may be greater than we think.

Also certain new or greatly increased demands for steel appear on the horizon. For example, to increase the oil pipe lines of the country by 27 000 miles, much of it trunk-line pipe of 20 inches in diameter, will require 6 million tons of steel. The search to find more oil is calling for more and deeper wells. Over 30 000 wells were drilled in 1946 as compared with the 1942–45 average of 23 700. And they average eight percent deeper. Thus the demand for casing and other steel incident to oil production is rising and will continue to rise sharply for many years.

The synthetic-fuel program sponsored by the Department of Commerce and urged by the Department of Defense calls initially for plants to produce two million barrels of oil daily. It will require 16 million tons of steel.

Regardless of what form housing construction takes, but particularly with some of the prefabricated designs, more steel will be used for building the needed homes of America.

These and similar increased or new steel demands superimposed on what appears to be steadily rising consumer consumption indicate a higher rate of usage for years to come. What that rate will be requires grade-A estimating.

One speaks nonchalantly of the steel industry as though it were a single unit, moving always as a unified body, and making decisions for the group as a whole. Such concept is misleading. The steel companies do have a well-organized national association (The American Iron and Steel Institute). At the same time competition is active. The decision as to whether this nation should have capacity for 91 million tons of steel per year, or 95 million, or something over 100 million as actually vehemently urged in some quarters, will not be a single decision of steel managements acting in unison. The total ability of this country to produce steel is the summation of what the many steel companies, the large and the small, have the plants for, each one being the result of the decision by the individual managements as to how much of the total market it can supply at a profit. It is, we can congratulate ourselves, the "free" enterprise system at work. No one believes it works perfectly—it simply works better than any other.

Rototrol in Steelmaking

"Give us more steel" is the cry echoed and re-echoed throughout industry. Steel men are trying—with new construction, new techniques, new tools. One such tool is Rototrol, which is being used to improve control and thereby increase production of existing equipment used in steel-making.

This Rototrol control equipment improves blooming-mill operation.

EVEN with a record-breaking peacetime production of steel, demand continues to outrun supply. To alleviate the situation manufacturers of steel are scrutinizing every possible means of increasing output.

One method is Rototrol*, the rotating regulator. The Rototrol is a small d-c generator similar in design and operation to a standard machine except for several additional field windings for control purposes. It has been used on both new installations and on existing equipment, replacing the old control system while main drive machinery is kept intact. Applied to a variety of steel-mill operations, such as blooming mills, cold-reduction mills, pickling lines, and arc furnaces, Rototrol is effective in securing smoother and more accurate control and reduced maintenance, with attendant beneficial results on production. Two applications are discussed here.

Rototrol on a Blooming Mill

In a blooming mill, an ingot at white heat and weighing several tons is reduced to a bloom by passing it back and forth continuously between a set of rolls. At the end of each pass the distance between rolls is reduced a "notch" and the direction of the ingot is reversed for the next pass. The total duration of each pass consists of the actual rolling time plus the time required to handle the ingot and perform other auxiliary operations at the end of the pass. Usually the active rolling time is but thirty to forty percent of the total. Consequently the inactive time required for auxiliary operations is very important. To reduce this period, auxiliaries are often driven by adjustable-voltage, Rototrol-controlled systems.

Applied to the main drive, Rototrol reduces the time required for reversal of the mill motor and maintains the active rolling speed at a higher level, both of which are beneficial to production. Current peaks are reduced, thereby decreasing commutator sparking, and vibrating relays and contactors are eliminated, further reducing maintenance. The net result is a decrease in down time and an increase in productive time.

On one 44-inch blooming mill, production was increased more than 20 percent by modernizing the electrical control of the main-drive motor. Rototrol replaced the former reversing-plugging system and reduced lost time sufficiently to enable rolling about 300 additional tons per eight-hour day.

The largest ingot rolled in the mill measures about 25 by 30 inches by 7 feet and weighs approximately 7.35 tons. It is reduced in 23 passes to blooms about 11 by 10 inches by 47 feet, the operation lasting about 2¼ minutes. Thus the average duration of a pass is under 6 seconds.

The mill motor is rated 5800 hp, 40 to 120 rpm at 600 volts direct current. It is supplied by a motor-generator set consisting of two 2500-kw d-c generators driven by an a-c wound-rotor motor. To reduce and smooth out a-c current peaks a heavy flywheel is mounted on the shaft. The electrical drive replaced a steam engine in 1921 and has been in continuous operation ever since.

Motor and generator armatures are connected in a series loop common for most adjustable-voltage drives. With the original equipment, motor and generator fields were energized from a constant-voltage bus and field currents were controlled directly by resistors and contactors. This type of control does not give the flexibility required for best blooming-mill operation nor is it readily adaptable to rapid motor reversal. Also, the time constants of the fields are high, which limits the rate of change of current and flux. The net result was that motor-reversal time was relatively long and generator voltage decreased with load.

To overcome these conditions, a Rototrol system was installed, with separate exciters for the motor and generators and two Rototrols to control the exciters. The system provided fast reversals by field forcing of both the motor and generator fields. This consists of applying 300 to 400 percent of normal voltage and current to change flux at faster rates. The motor Rototrol acts as a current regulator. It operates in conjunction with an auxiliary current-limiting Rototrol, which functions through the motor exciter to limit peak regenerative

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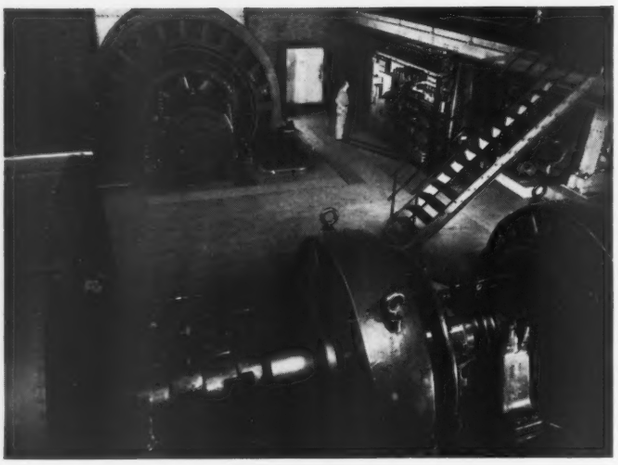
Prepared by L. H. Berkley from information furnished by Erling Frisch and J. R. Erbe of Westinghouse Electric Corporation.

*The principles of operation of the Rototrol are discussed in the following issues of the Westinghouse ENGINEER: May, 1942, p. 51; August, 1942, p. 75; November, 1945, p. 188; and July, 1947, p. 121.



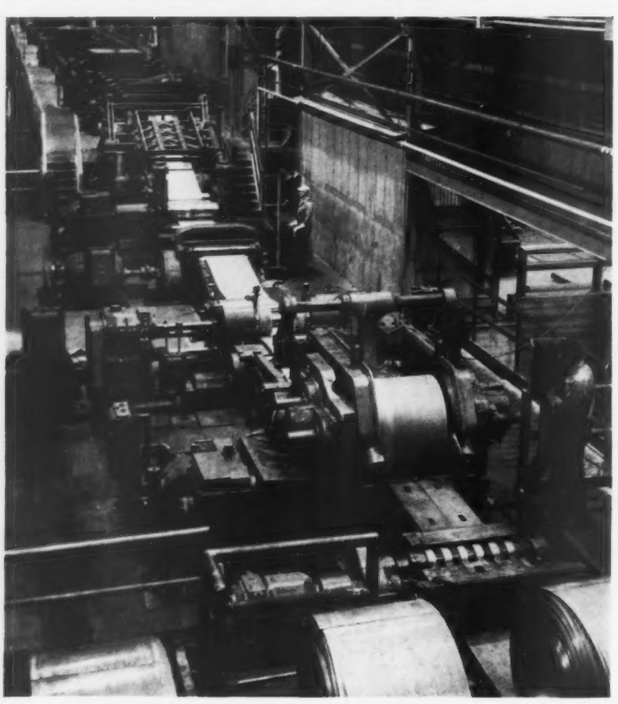
The motor room of the blooming mill. The driving motor is in the rear; the motor-generator set in the foreground.

current in the motor armature to a safe value and yet provide higher average current, thus reducing reversal time.

The generator Rototrol functions as a voltage regulator to maintain generator voltage at the value desired for each phase of the rolling cycle, independent of rolling load and speed of the motor-generator set. In addition to aiding rapid reversal, it maintains the generator voltage and consequently speed of the mill motor at a high value during the rolling period.

Rototrol control reduced the d-c regenerative current peaks that occur when the motor is decelerating from 6000 to 4000 amperes and the accelerating peaks from 10 000 to 6500 amperes with an occasional 7500-ampere maximum. This reduction in peak currents, combined with better correlation of generator voltage and motor field strength over the complete speed range, reduced the I^2R losses in the d-c machines. Snappier and more efficient operation maintains speed of the flywheel m-g set at a higher level. Because of this higher speed, losses in the secondary slip regulator are reduced which prevents its overheating and decreases the lost production time previously encountered due to maintenance. These factors, smoother and snappier control and reduced overall maintenance, resulted in an increased output from approximately 162 to almost 200 tons per hour. Such a large increase in production is unusual. However, smoother control and reduced maintenance can usually justify a Rototrol installation.

The high-speed pickling line from the delivery end.



Rototrol on a Pickling Line

Hot-rolled steel must be pickled prior to cold rolling to remove scale, else the scale will be rolled into the metal and cause pinholes in the finished sheet. Pickling is accomplished by passing the hot-rolled sheet through a series of tanks containing an acid solution. A pickling line, which may be as long as 800 feet, consists of three sections: an entry or welding section, pickling tanks, and a delivery or shearing section.

Threading a sheet through the multitude of tanks and guide rolls is a time-consuming operation. Therefore, at the end of each coil, the entry section is stopped and the end of the coil being pickled is butt-welded to the end of the next coil. This gives continuous operation of the line. At the delivery end, the sheet is rolled into larger coils which are sheared when the desired length is reached and then sent to the cold mill. Coils from the hot mill are small, being limited by the size of the original slab. This would limit the running time of modern cold mills which operate at speeds approaching a mile a minute. Pickled coils are therefore sheared in longer lengths.

While the welding operation is essential, it is an inconvenience. About 30 seconds are required to make the weld, which must be capable of withstanding cold reduction. During this period the sheet cannot be standing still in the pickling tank else it will be overpickled. Consequently it is necessary to have a storage loop that gathers sheet in the form of a huge "U" during continuous operation and feeds the pickling tanks during welding when the entry section is at a standstill. After welding, the entry end is automatically restarted and brought up to full speed to resume feeding the storage loop.

One such pickling line using Rototrol control operates with an entry speed of 1400 feet per minute and a pickling speed of 600, the difference being used for the storage loop. These speeds are approximately double that of any previous pickling line, which complicates the control problem. At a pickling speed of 10 feet per second, if the time required for the entire welding operation (including to stop and restart the entry section motors) were 50 seconds, the length of sheet stored would be about 400 feet. This is undesirable and can be reduced by reducing the time required to stop and start the three motors in the entry section. These motors range from 60 hp to 350 hp and are stopped in 3.5 seconds and started in 4.5 seconds. The usual time required is 7 seconds and 9 seconds. In effect the length required in the storage loop is reduced 60 feet. Rapid stops and starts are very desirable when welding takes longer and the loop is almost exhausted.

Another advantage comes in the recoiling operation on the delivery end. When the coil reaches its proper length the speed is cut down from 600 to about 150 feet per minute and the sheet is sheared. The coiler motor is then stopped, the coil is removed, and the motor again started. During this period the sheet is exposed more than necessary to the acid solution. This time is reduced approximately 50 percent by rapid acceleration and deceleration of the delivery end. In this application, a new one, the advantage of Rototrol control is primarily in smoother, more flexible operation.

Gyroscopes and Their Applications

When M. Foucault in 1852 showed how a spinning mass maintains its position in space independent of the earth's rotation—when in 1908 Anschultz added weighted damper members to Foucault's gyroscope and made a true-north-seeking instrument out of a toy—a new tool was created, which has remained substantially the same. Only the applications differ—but to an extent hardly believed possible a decade ago.

K. A. OPLINGER, *Research Laboratories, Westinghouse Electric Corporation*

THE dancer uses his spinning body as a gyroscope to hold himself erect when balanced on his toes. The athlete spins his discus as he throws, so that gyroscopic effect stabilizes it, causing it to act as an air foil and travel farther. The small boy soon learns that his hoop, which will not stand upright by itself, will do so if rolled along the ground.

The gyroscope does not appear to obey the generally known principles of force and reaction—force applied to a gyroscope results in motion at right angles to the plane of the applied force. At first glance it appears to be simply a spinning mass and if an attempt is made to determine reactions about three

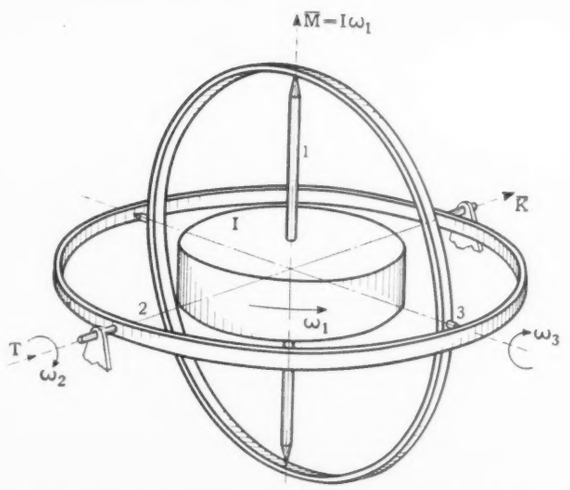


Fig. 1—The torque required to turn axis no. 2 when the rotor is spinning is much greater than when the rotor is stationary; this is rigidity. Torque applied to axis no. 2 causes rotation about axis no. 3; this is precession.

axes moving simultaneously, a complete general analysis leads into advanced principles of dynamics and mathematics. Fortunately motion of most gyroscopes in practical applications can be understood without making a complete analysis of a freely spinning mass.

Basic Principles of the Gyroscope

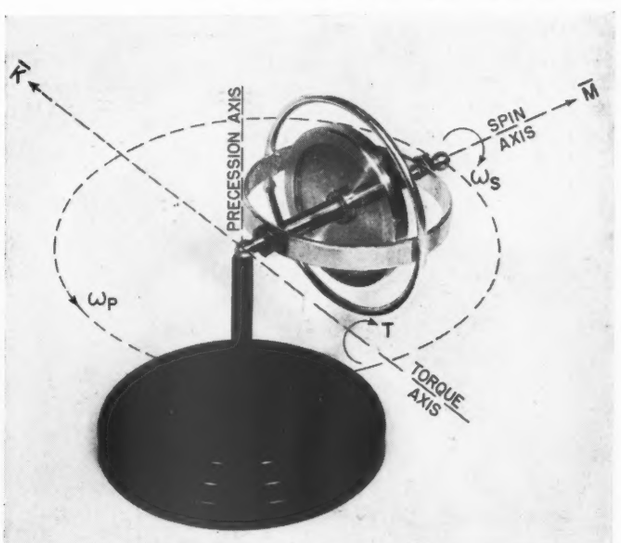
By rolling his hoop the small boy gives it angular momentum so that it resists forces trying to change its plane of rotation; this resistance is referred to as "rigidity in space." This ability to maintain a fixed plane of rotation is one of the fundamental properties of the gyroscope. Although any mass in motion tries to maintain its direction in space, this effect is more pronounced in a spinning mass or gyroscope because, by making the angular velocity high, a large angular momentum can be imparted to a rotating body having a relatively low moment of inertia.

Also, the boy with the hoop unconsciously applies a second fundamental principle of the gyroscope—precession. If he touches the side of the rolling hoop lightly at the top he easily changes its direction of travel. This change, precessional motion, results from application of a small torque about a horizontal axis at right angles to the spin axis, causing the hoop to precess or turn about a vertical axis perpendicular to both spin and torque axes.

These two basic principles are more apparent if observed on a free or neutral gyroscope supported in gimbal rings as shown schematically in Fig. 1. If an attempt is made to rotate spin axis no. 1 rapidly about either of the horizontal axes the spinning rotor resists angular displacement with a relatively high reaction torque. This torque tends to hold the spin axis fixed in space with respect to angular displacement but does not oppose linear motion of the gyroscope.

When the rotor of Fig. 1 is spinning about axis no. 1 with an angular velocity ω_1, a couple or torque applied to the gimbal supports about axis no. 2 to impart an angular velocity ω_2, causes the spin axis to rotate or precess about axis no. 3 with a velocity ω_3. This latter rotation about an axis at right

Fig. 2—The weight of the gyroscope causes a torque about an axis at right angles to the spin axis. This results in precessional motion about an axis at right angles to both.



angles to both the axis of spin and applied torque is gyroscopic precession. It stops when the spin axis, no. 1, moves 90 degrees and aligns itself with the applied-torque axis, no. 2.

The direction of precession is fixed by the directions of spin and of the applied couple, and is such as to result in an increase in angular momentum about the axis of the applied couple. Therefore precession is in the direction that places the vector of spin torque in the same direction as the vector of applied torque. The direction of a torque or angular-momentum vector is conventionally taken as the direction a right-hand thread moves if turned by the torque. In Fig. 1, then, with the gyroscope rotor turning counter-clockwise to establish an angular momentum vector $\overline{M}$ pointing upwards, a clockwise couple represented by ω_2 and vector $\overline{K}$ causes a clockwise precession of the spin axis, ω_3.

Although gyroscopic effects are observed in practically all forms of rotating bodies, it is customary to think of a gyroscope as a rotating mass having certain practical restrictions on its moment of inertia and motion. Six degrees of freedom are required to analyze mathematically a free mass moving in space, three for linear motion in three mutually perpendicular planes and three more for angular motion about three mutually perpendicular axes. But, if the center of gravity of the mass remains fixed, only angular motion can occur and hence only three degrees of freedom are required. A gyroscope having three degrees of angular freedom is called a free or neutral gyro. Its spin axis can move freely in any angular direction.

To simplify the analysis, the gyroscope is made so that the spinning mass is the principal inertia and is statically and dynamically balanced about its axis; also all moments of inertia are equal about the axes perpendicular to the spin axis and passing through the centroid. Consequently, the free gyroscope, with one degree of freedom taken by the spinning mass, is relatively simple to analyze. Since rotation is usually constant, only two degrees of freedom remain to be considered, those of input and output torques and motions.

Models and Effects

A toy gyroscope top demonstrates precession and at the same time indicates the magnitude of precession torque. Although the top, Fig. 2, when rigidly supported has only one degree of freedom, that of the spinning mass, three degrees are obtained by supporting only one end. When one end of the spinning top is placed on a support with the spin axis approximately horizontal, the axis dips slightly with several small oscillations and then precesses in a horizontal plane about a vertical axis. The weight of the gyroscope, acting about the point of support, applies a torque to the spin axis. The resulting precession is continuous since the applied torque rotates with the precession. Therefore, the spin vector, in trying to align itself, is continually moving toward the position occupied by the torque vector.

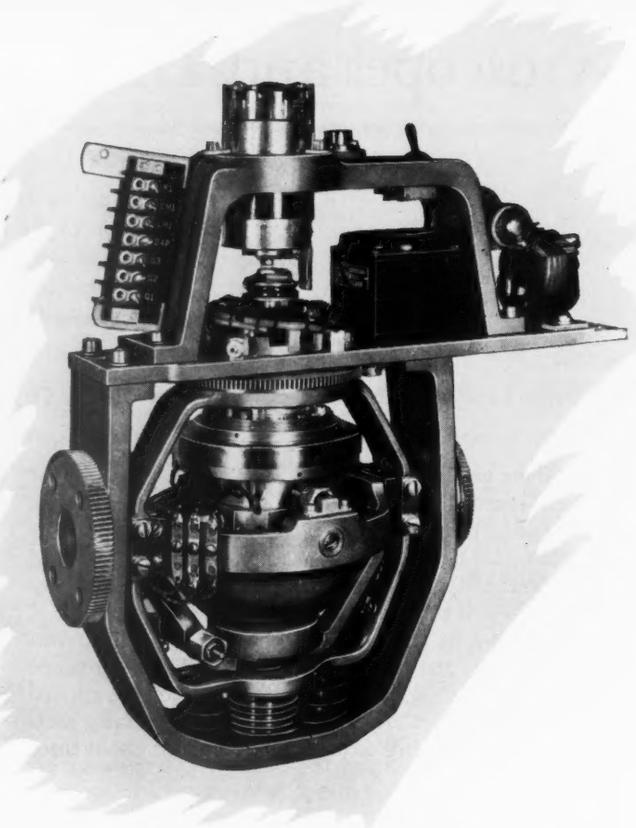


Fig. 3—This position gyro is used to supply a true vertical reference in the presence of roll and pitch.

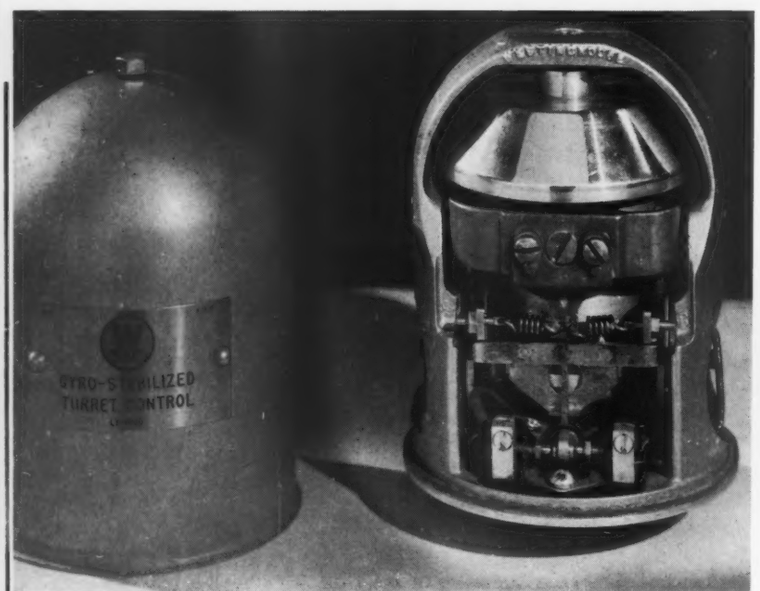


Fig. 4—This gyro-stabilized turret control for airplanes employs a rate gyro.

The ability of the gyroscope top to support itself in this manner by precessing can be explained by the simple relation

$$T = I\,\omega_s\,\omega_p$$

where I is the moment of inertia with respect to mass of the spinning wheel about its axis, or mass times radius of gyration squared (pound-inch-seconds^2), ω_s is the spin velocity, ω_p the precessional velocity (both in radians per second), and T the torque (pound-inches) acting about a horizontal axis perpendicular to both the spin and precession axes. The units of torque in the weight or force system are pound-inches. For consistency, the units of moment of inertia must be in the same system. Dimensionally these units are

$$I = \frac{W}{g} \times R^2 \text{ or } \frac{W}{LT^{-2}} \times L^2,$$

where W = weight, L = length, and T = time. Dimensions are cancelled to equal WLT^2 or pound-inch-seconds^2.

With constant spin velocity, the top would precess in a fixed plane at a constant rate were it not for the friction loss at the point of support. This loss is supplied by the potential energy of the top, which decreases slowly as its free end falls. Where the angular momentum of the top is decreased by

friction at the spin bearings, the precession rate of the top must increase as the spin velocity ω_s decreases to maintain the balance between gyroscopic torque and torque produced by weight of the top. In many toy gyroscopes friction about the spin axis is so large that its angular momentum rapidly decreases, soon increasing precession rate to the point where the top falls off its support.

In determining the magnitude of forces obtainable from gyroscope rotors, reference to the simple top of Fig. 2 shows that it supplies a torque equal to the moment of its weight about the point of support, approximately 0.5 pound-inches. The rotor has a moment of inertia of 0.00025 pound-inch-seconds^2 and can be given a spin velocity of approximately 300 radians per second by means of a string wound about the axle. Substituting these values in the torque equation, precession velocity is

$$\omega_p = \frac{T}{I \times \omega_s} = \frac{0.5}{0.00025 \times 300} = 6.67 \text{ radians per second.}$$

If, then, the top is supported as shown in Fig. 2, its precession velocity, ω_p is 6.67 radians per second. Also, if it is supported in a gimbaled system, as in Fig. 1, and given a velocity of 6.67 radians per second about axis no. 2, a precession torque of 0.5 pound-inches appears about axis no. 3.

Angular momentum, or product of moment of inertia and spin velocity, is a convenient constant for evaluating effectiveness of a gyroscope. For example, the top of Fig. 2 has an angular momentum of 0.075 pound-inch-seconds and therefore develops a torque of 0.075 pound-inches if given a velocity of one radian per second about an axis at right angles to both the spin and torque axes.

Types of Gyroscopes

Practical applications of the gyroscope are divided into two general classifications of position or rate type, depending upon the principal gyroscopic effect employed. The gyroscope is classified as a position type in applications where it supplies a position reference. Position gyros are freely gimbaled and make use of the "space rigidity" effect which tends to hold their spin axis fixed in space in the presence of angular disturbances. In applications where the primary function of the gyroscope is to sense angular velocity or rate the gyro is classified as a rate type.

Position Gyroscopes

A position gyroscope is freely gimbaled so that its spin axis can move in any angular direction. If the spin axis is placed at any angle, its rigidity tends to maintain it at that angle.

Spin axis no. 1 of the gyro in Fig. 1 can be used on a ship to supply a true vertical reference in the presence of roll and pitch. To make use of this reference it is necessary to provide a measure of the angular deviation between the gyroscope and the ship. One possible method is to use two magnetic pick-up coils to measure angular displacement about axes nos. 2 and 3. The pick-up coils are mounted to move with the ship and their associated armatures are attached to the inner gimbal so that output signals are proportional to the roll and pitch angles of the ship.

In attempting to use a position gyroscope for an absolute position reference, it is soon discovered that "rigidity in space" is only a relative term. A free gyroscope can be made extremely rigid in space or resistant to angular displacements, by giving it large angular momentum. But regardless of how large the angular momentum, the gyroscope never remains absolutely fixed in space. Large angular momentum merely results in a slower precession or drift for a given applied couple. Small couples due to bearing friction or air resistance are always present and even the smallest will in time cause the gyroscope to change position. The rate of movement depends on the care taken in design and drift of the spin axis and varies from a few degrees per minute to a few per day. Consequently, the problems associated with the application of position gyroscopes are more numerous than those found in the application of rate gyros. It is necessary to keep all external torques on a position gyro extremely low since any torque results in precession and angular deviation of the position reference. This requires considerable care in the design and construction of the gimbal supports and in the servo-system used to measure the positional deviations of the source.

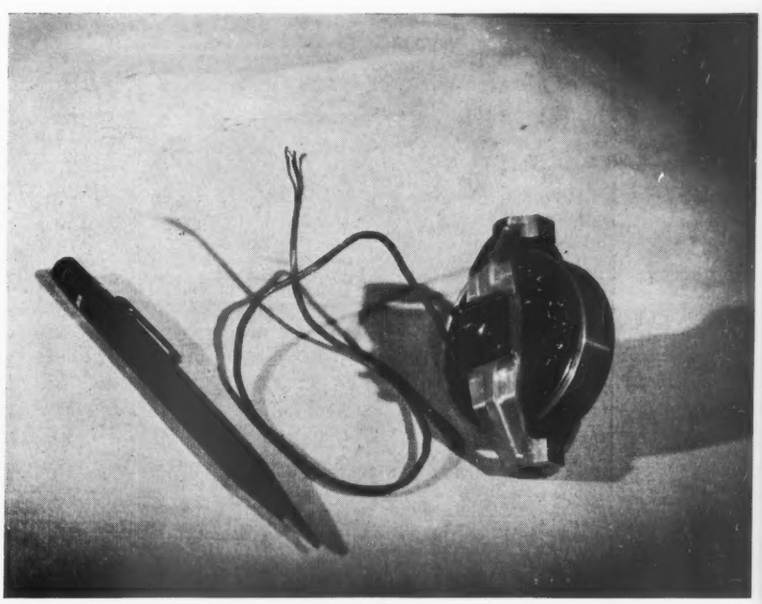
To prevent a continuous drift of the spin axis from the vertical due to external torques, a free-position gyroscope is usually loosely coupled to a pendulum. Such a gyroscope is shown in Fig. 3. The pendulum serves as a reference for true vertical and is coupled to the gyro by a small electromagnet that generates eddy currents in the rotor. When the gyroscope is vertical, electromagnetic forces acting on it are balanced; when not vertical, unbalanced forces produce a torque on the gyroscope causing it to precess to the vertical position. In this design, the gimbal assembly is slowly rotated to cancel the disturbing effects of unbalance and unequal bearing friction. This position gyroscope with its servo-system, can supply output signals representing true vertical in the presence of roll disturbances as great as plus or minus 30 degrees, with an accuracy of one tenth of a degree.

The fact that a position gyroscope supplies the stimulus for a position-regulated system also increases problems of stabilization as compared with those experienced with a velocity-controlled system using a rate gyro.

Rate Gyroscopes

The rate gyroscope, Fig. 1, has only one effective degree of freedom since the outer gimbal is rigidly fixed to the system being controlled, which might be, for example, an airplane. If axis no. 2 is fixed parallel to the longitudinal axis of the aircraft, angular velocity in roll results in precession of the gyro rotor about axis no. 3. The direction and magnitude of the

Fig. 5—The "inside-out" gyroscope rotor gives a high angular momentum per unit weight.

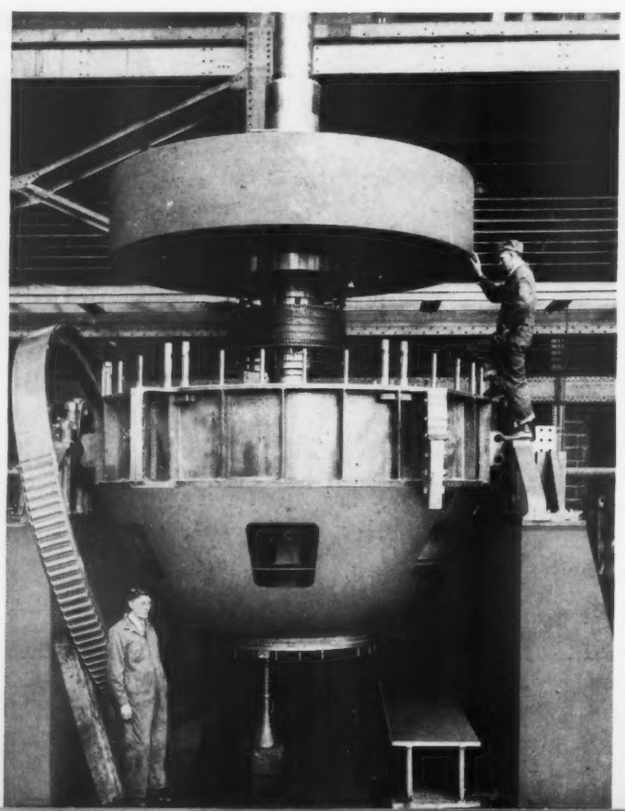


precession torque depend upon the direction and rate of roll of the airplane. Pick-off and amplifying elements responding to precession about axis no. 3 control the ailerons and therefore the roll velocity of the aircraft.

A simple rate gyro is shown in Fig. 4. Motion about axis no. 2, which is parallel to the plane of the paper produces a precession about axis no. 3, perpendicular to the paper. Motion about the precession axis is restrained to a very small angular deflection by two stationary contacts mounted on the assembly base. A common, movable contact is fixed to the gyroscope. By placing a slight unbalance in the gyroscope wheel, the center contact is given a forced vibration so that one pair of contacts is continually made and broken. The frequency of contact equals the frequency of vibration but the contact duration is proportional to the precession torque. Thus effective current is proportional to torque applied about the precession axis.

This gyroscope is built to coordinate simple gyroscopic stabilization with an externally supplied signal. This is accomplished by placing two small electromagnets on the frame supporting the gimbal. The magnets are energized in proportion to the magnitude and direction of the signal and supply an equivalent torque about axis no. 3. A gyro-stabilized, velocity-controlled system consists of mounting this rate gyroscope on a rotating output member so that the gyro responds to the angular velocity of the system. The contacts control a hydraulic or electric servomechanism whose output velocity depends in both magnitude and direction on the resultant of the torques supplied to the gyro by both the electromagnets and the angular velocity of the system. When torque from an external signal closes one pair of gyroscope contacts the entire system is rotated and the gyro develops an opposing precessional torque proportional to the system's angular velocity. When the two opposing torques are equal a hovering contact condition is obtained resulting in a stabilized velocity. Any deviation in velocity that may result from load variations or angular velocity in space gives a change in pressure at the hovering contacts and causes the servomechanism to supply additional output torque to resist the deviation. Velocities as low as thirty degrees per minute have been controlled and stabilized by this small rate gyroscope.

Fig. 6—This huge rate gyro stabilizes a 5000-ton yacht by limiting the roll due to impacts of waves.



Gyroscopes in Action

In some cases, as in the gyro-stabilizer developed for tank guns, both position and rate gyroscopes have been combined in one system. But the requirements of most applications are satisfied by either one type or the other.

Bombsight Gyro

The small gyroscope of Fig. 5 is approximately the same size as the toy gyro-top, but it has ten times the angular momentum. Its total weight is only ten ounces but an angular velocity of one radian per second causes it to develop a torque of 0.75 pound-inches. This gyroscope is designed for a bombsight where minimum size and weight are important. Its umbrella-type, hysteresis-driven rotor runs at a synchronous speed of 12 000 rpm on a 3-phase, 400-cycle power supply. It can be used either in a rate- or position-controlled system.

Anti-Roll Gyro

At the other extreme in practical designs are large gyroscopes for stabilizing ocean liners and large yachts. The eleven-foot-diameter rotor of a large gyro whose total weight is 100 tons is shown in Fig. 6. This unit stabilizes a 5000-ton yacht by limiting its roll to only a few degrees even in a rough sea. The rotor is driven at 930 rpm by a 275-hp, 3-phase, squirrel-cage motor mounted directly on the shaft. At this speed its angular momentum is approximately 5 000 000 pound-feet-seconds. During stabilization, when the maximum precessional velocity may be 0.5 radian per second, the gyroscope will supply a stabilizing torque of 2 500 000 pound-feet, usually sufficient for passenger comfort.

Antihunting Control in Servo-systems

The use of a gyroscope for antihunting control in servo-systems is one of the most interesting applications. First described by C. R. Hanna of Westinghouse Research Laboratories, it has been employed in electric drives for tank turrets and radar-tracking antennas.

In a position-controlled servo-system, the stiffness (the torque developed at the output per unit angular error) must be kept high if high position accuracy is required. If the servo-system has several large time delays, it is difficult to obtain high stiffness along with a sufficient amount of system damping. In such a case some form of antihunt device is generally needed to correct this condition.

Antihunt is obtained by introducing a rate or velocity response in a position-controlled system. Resistance-capacitance circuits are often used for this purpose. In these circuits the current through the resistance is proportional to angular deviation and current through the capacitance is proportional to its rate of change. Such a circuit is effectively employed where electronic amplifiers are to be used.

If electronic amplifiers are not available, a small gyroscope can be used to respond to angular velocity of the system and thus supply the desired rate response for antihunting. A schematic of the servomechanism used for the tracking system of an SCR-270 radar antenna is shown in Fig. 7. An angular movement θ_i of the input for tracking results in an angular displacement θ_o of the antenna. Any angular difference between the input and output synchros ($\theta_i - 72\theta_o$) appears as an error θ_e at the differential synchro. The angle θ_e is applied to a small gyroscope spring-centered about its pre-

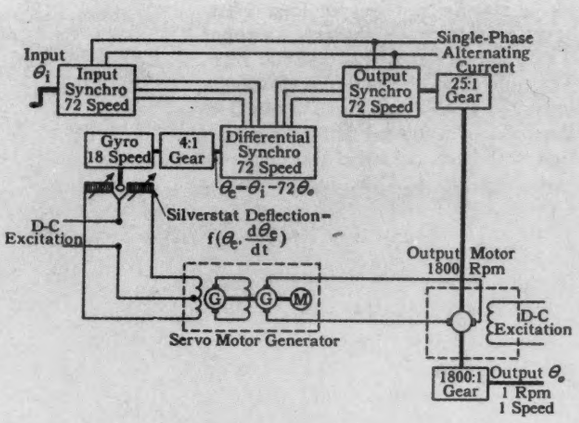


Fig. 7—The angular movements of the input and output synchros are compared by the differential synchro, whose output, θ_e, is the difference or error between the two. This output angle is applied to the gyro, which deflects either Silverstat, depending on direction of error. Deflection is a function of not only error but also rate of change of error. The combination gives improved performance. Principal time delays are in motor and generator field and armature circuits.

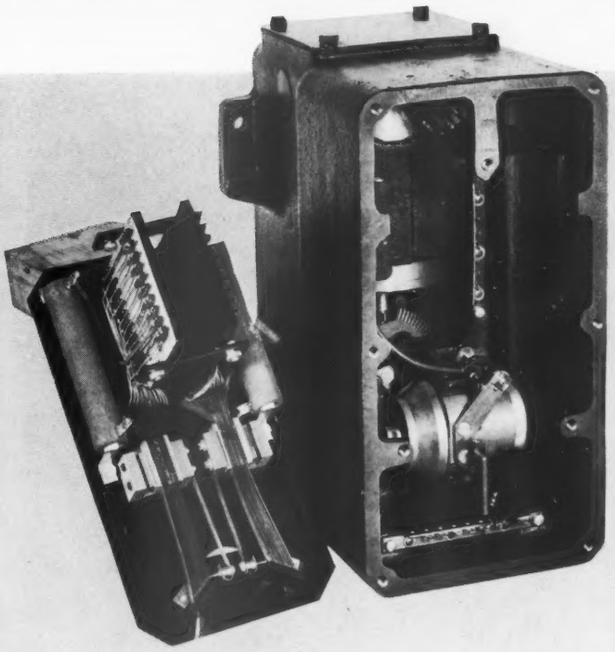


Fig. 8—This gyroscopic control is for a radar antenna. The Silverstat is removed to reveal the operating arm.

cession axis so that the entire assembly is deflected in proportion to θ_e. This deflection, θ_e, is added to the gyroscopic precession it causes, which is proportional to the rate of change of θ_e. The total deflection is applied to a Silverstat (a multiple-contact resistance assembly) whose output current is then a function of both error angle and rate of change of error angle. The differential synchromechanism and gyroscope unit for this antihunt control are shown in Fig. 8.

Automatic Pilot

The assembly of three small rate gyroscopes shown in Fig. 9 (one more is mounted in the rear) is part of the control for a new automatic pilot for airplanes. Since it uses rate gyroscopes, the type W-1, as it is known, retains control of the plane during rapid accelerations in any direction and during any maneuver, even the most extreme loops and rolls. Because of this ability to retain control, the new pilot, now in the test stage for conventional planes, may be applicable to guided missiles and pilotless aircraft. Other features are light weight, simplicity, a direct inbuilt means of banking control, and a reduction in power requirements.

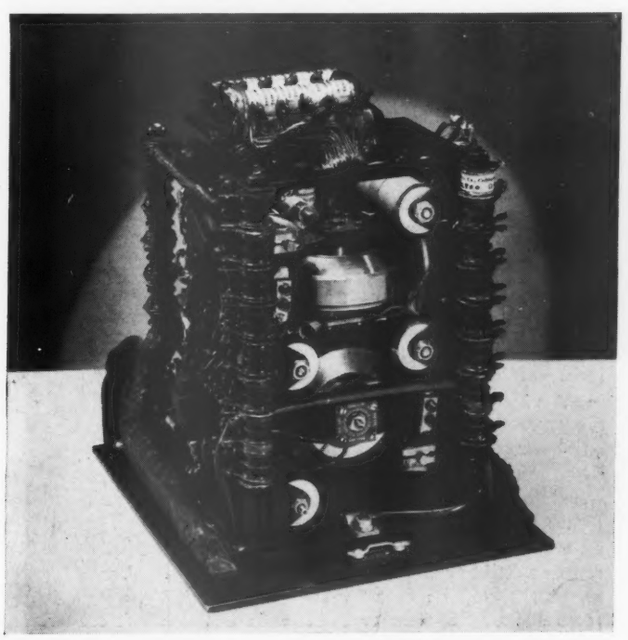
The gyroscopes employed are those of Fig. 5. Being rate gyros, the outer gimbal of each is rigidly fixed to the plane so that motion about one axis is then caused by angular deviation of the airplane. The second axis of each gyroscope is the spin axis and the third is the precession axis, about which the gyroscope moves to supply a signal. Each gyro can control motion of the plane about one axis only and consequently three gyroscopes are needed for complete control, one for each of the three principal axes.

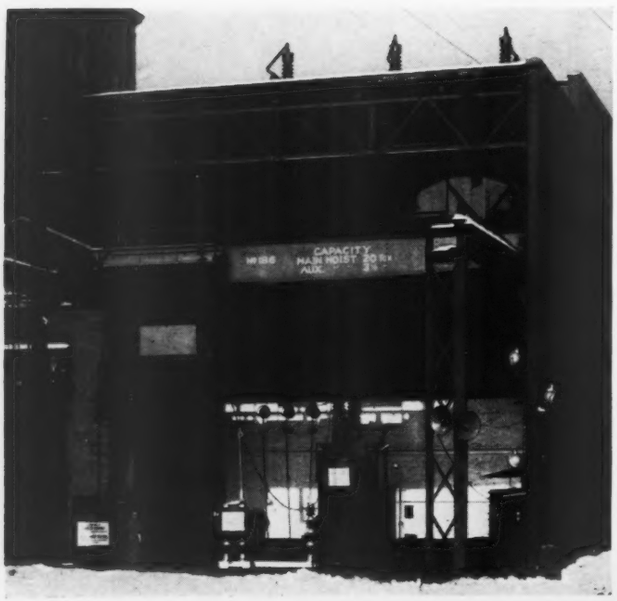
Conclusion

The present commercial importance of the gyroscope results from the impetus given it by the expansion of air transportation and the second World War. The airborne gyroscope was used to solve numerous requirements unique to aircraft so that today there are few large airplanes that do not depend on its aid in navigation and automatic control. The war brought forth many new applications for the gyroscope and this country alone required well over one million to meet its military needs. These new uses, however, have added little to the basic gyroscopic principles, but rather, have led to refinements in mechanical and electrical design and to new servosystems so essential for their practical application.

Among the more important future applications for the gyroscope will be the improved automatic control, the type W-1, for piloted and pilotless aircraft. Future elevators may use the gyroscope to obtain accurate landings at floors, and railway coaches may be correctly banked when rounding turns to provide greater passenger comfort and faster operating speeds by means of a gyro-pendulum.

Fig. 9—Heart of the new automatic pilot are three rate gyroscopes whose rotors spin at 12 000 rpm.

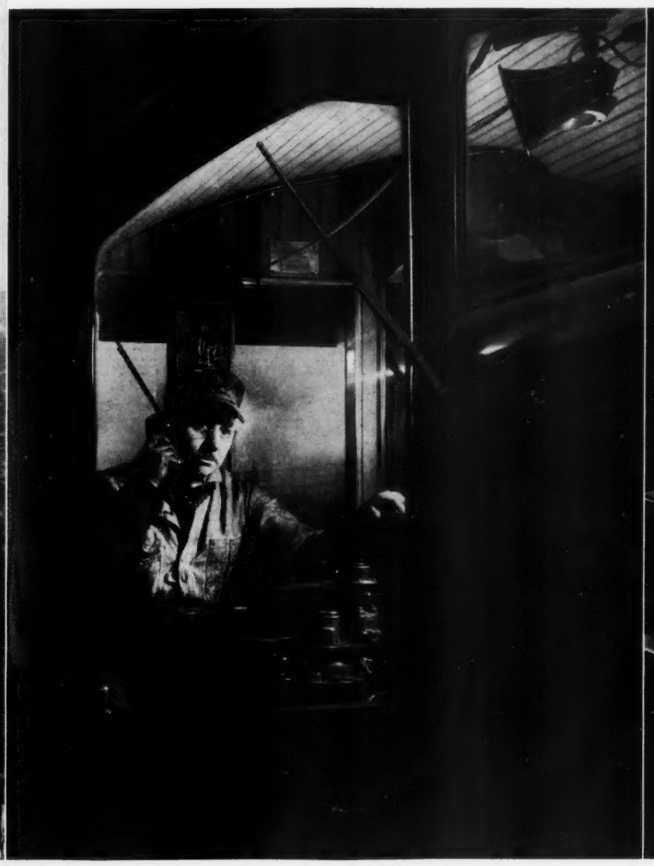


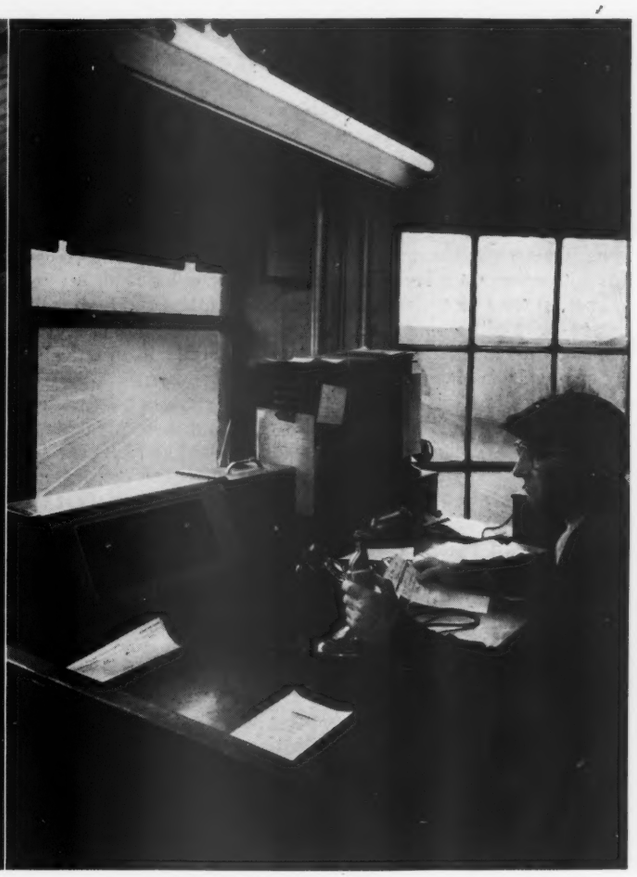


THIS circuit breaker in the high-power laboratory test cell at East Pittsburgh has interrupted the largest amount of power ever handled at 345 000 volts. The equivalent of 5 million kva was interrupted in less than three cycles from inception of a bolted fault to extinction of the arc. A second test consisted of flashing over a 230-kv insulator string to simulate an arcing fault to ground. The breaker is the embodiment of experience obtained in designing breakers for interruption of 10 million kva on the 230-kv power system at Grand Coulee.

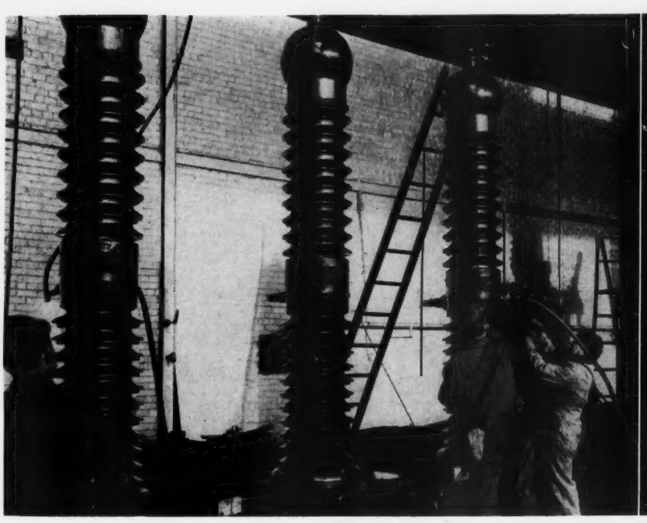
THE experience of the tuna boat, *Normandie*, with war-surplus radar, was so successful in permitting operation and navigation when other fishing boats were stalled by fog that it has been re-equipped with a commercial-type radar set. With this new equipment, of which the antenna dome is shown above, maintenance has been greatly reduced. It has already made bait fishing possible in dense fog as well as entering and leaving the harbor on schedule. Trials are now being made to locate by radar circling swarms of sea birds that indicate the presence of fish. A representative pattern of obstacles about the ship is given by the partial picture of a radar-scope screen in action.

A 25-WATT, static-free, FM railroad radio is bringing efficient and streamlined operation to a local industrial railway. The system, which handles raw materials and semifinished and finished products for a steel mill, encompasses about 36 miles of railroad track over a five-mile stretch. Prior to installation of the radio, locomotive operators, upon completing a task, were required to ride back to the yardmaster's office or to the nearest telephone for the next assignment. Now they merely pick up the adjacent radio telephone. Also, the yardmaster has each man at his fingertips.





A GERMAN 110-kv, oil-poor breaker has been on test (below left) in the high-power laboratory at East Pittsburgh. It is a single-arc type rated at 1.5 million kva. Specially designed for the extremely severe duty of driving a log chipper is the synchronous motor (below right). The rapidly varying shocks as the knives bite into the logs cause torque variations up to 800 percent of normal.



Stories of Research

Plastics—Theme and Variations

THE plastics industry has grown so fast that the art is miles ahead of the science. That a particular combination of resins and filler should meet a specific mechanical, electrical, or decorative need is perhaps all the plastics design engineer need know about many of the materials with which he works. But more and more the research man is asking "why?" and "how?" The answers are adding to the store of fundamental scientific knowledge that must be the basis of any art.

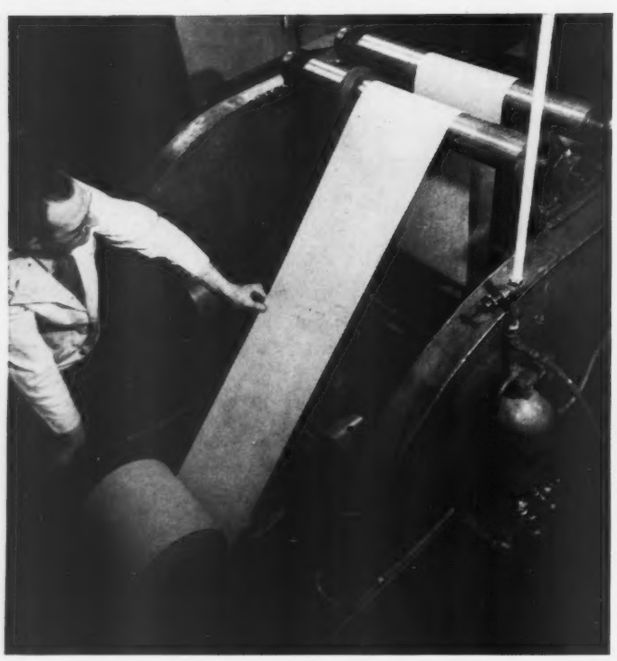
M. P. Seidel, R. J. Heinritz, and R. H. Runk of the Westinghouse Research Laboratories have enlisted "assembly-line" techniques to speed their investigations in this complex field. An experimental treating tower, along with resin kettles and hydraulic presses—virtually a plastics plant in miniature—enables the three men to reproduce materials for fundamental study in practically any combination of resin and filler.

Fillers of all types—cloth, paper, fabric, etc.—can be pulled continuously through made-to-order resin baths, impregnated, dried, and later pressed into laminated boards. The fillers can be impregnated at any temperature from 100 degrees to 700 degrees F. They can be dried as fast or as slow as the researchers want by means of flexible air-flow controls that can be varied from zero to 500 cubic feet per minute. Filler speeds range from virtual standstill to 80 inches per minute. After the fillers have been treated, they are trimmed to size, stacked between mirror-finish press plates, and bonded by applying heat and pressure.

A typical problem being attacked is an investigation of paper fillers. Although paper is the workhorse of the laminating industry, much fundamental knowledge of its various properties is lacking. The three men are attempting to fill some of these gaps by extensive tests involving combinations of several resins with many kinds of paper. In so doing they hope to find paper-filled laminates that have better dimensional stability, low moisture absorption, easy machineability, high mechanical strength, and improved electrical properties. More important they hope to find out the reasons behind these properties and thereby reduce the selection of constituents to an exact science. When this is attained, a specific need will be fulfilled simply by selecting ingredients of the plastic for their known characteristics. The final product will then be "pre-tailored" rather than decided experimentally by a trial-and-error method.

One significant fact already turned up by the researchers is the wide variation in performance among different types and grades of paper even when treated with the same resin. Where one paper gives good dimensional stability and low moisture absorption, another treated with the same resin behaves differently in these respects. Seidel, Heinritz, and Runk believe that a complete answer to problems like these will add much-needed knowledge to the science of plastics, particularly in the field of laminates.

M. P. Seidel gives the "tackiness" test to this resin-impregnated paper as it emerges from the oven of the experimental treating tower. Almost any combination of resin and paper can be produced by this versatile tower.



Tiny Jet Engine Builds a Fire

AT one time "building a fire" meant simply arranging some paper, sticks, and wood in a heap and lighting a match to it. But since the advent of jet engines, the term has acquired a new meaning, that of the highly complicated process taking place in the combustion chamber.

In a new laboratory primarily concerned with building jet-engine fires, the secrets of combustion are being unfolded. One investigation concerns a tiny cylindrical ram-jet engine, a prototype, perhaps, of units that may drive supersonic aircraft of the future. The engine consists essentially of a diffuser of gradually increasing area so that air passing through it decreases in velocity and increases in static pressure, a combustion chamber, and an expansion nozzle through which the gases escape. A ram-jet

As research engineer E. A. DeZubay flips the ignition switch, flames explode from the rear of the ram-jet engine, propelling it forward at a make-believe speed of 375 miles per hour.

A valuable tool for the analytical chemist is this micro-combustion furnace (right) in which extremely small quantities of material—down to one ten-thousandth of an ounce—can be vaporized for analysis. Here technician E. J. White charges the furnace.

These artificial "raindrops" are being used in a research project for a study of the weather-forecasting possibilities of radar waves. During the war, radar observers noted that the 1.25-cm, k-band of wavelengths gave very poor results during rain, snow, or conditions of high humidity. This effect was attributed to absorption and scattering of microwave energy by the rain, snow, or water vapor. Radar waves are first "fired" at a screen that absorbs nearly all of the microwave energy. The amount of scattering is picked up and measured at different locations by an ultra-sensitive receiver. Then the process is repeated with a raindrop mounted on the screen. The difference in energy scattering is indicative of the effect of the raindrop. The study may make it possible to map and trace the formation of storm clouds in terms of particle size, density, distribution, and other important factors, bringing, perhaps, long-range weather forecasting.

engine has no air compressor as such, but relies instead on the velocity of flight and the diffuser to build up the required air pressure. Air simulating its forward velocity is supplied to the small cylindrical engine by a larger cylinder, which provides a powerful blast of compressed air equivalent to a speed of 375 miles per hour. This is comparatively slow for ram-jet engines which operate at greatest efficiency at about 1000 miles per hour.

Air entering the engine is "compressed" by the diffuser. It then flows to the combustion chamber where fuel, acetylene or hydrogen, is injected and ignited by a spark plug. Combustion, once started, maintains itself. At the rear end of the engine the hot gases expanding through the nozzle supply a thrust in a direction opposing the compressed air.

A strain gauge attached to the engine support compares the ram-jet thrust with the drag produced by the compressed air. The result, flashed on a screen, indicates which is greater and the magnitude of the difference.

Test-Tube Detective

LOOKING for the proverbial needle in a haystack would be a sailor's holiday for the analytical chemist—and an easy one at that. Quietly and unobtrusively, he is accustomed in a day's work to tracking down much more elusive items with rich benefits for the metallurgist, chemist, physicist, and other of his fellow scientists. Quite often what he finds may be as impalpable as a fingerprint, yet it may weigh heavily in the solution of a particularly vital problem.

The "case book" of R. H. Wynne, who heads up the analytical group at Westinghouse Research Laboratories, is filled with such instances. They range all the way from determining the percentage of carbon in a sample of steel to finding out why certain alloys wouldn't harden.

The latter is one of Wynne's recent prize examples of test-tube sleuthing. Two copper alloys with almost identical chromium content—added to provide hardness—were subjected to the same heat treatment and quenching. Alloy "A" hardened as usual, but alloy "B" didn't. The metallurgist was stumped and turned to the analytical chemist for help.

The first probe disclosed that in alloy "B" the percentage of chromium in solution was only one fourth of the total chromium present, while in alloy "A" it was nearly one half. Because only the quantity of chromium in solution is actually alloyed with the copper, Wynne felt pretty confident that in the small percentage of soluble chromium in alloy "B" lay the explanation of its failure to harden as expected.

His next step was to find out what factor was keeping additional amounts of chromium from going into solution. Here the x-ray spectrophotometer revealed a key clue. The insoluble chromium was examined and the x-ray "finger" pointed to the possible presence of chromium aluminate or chromium phosphide. The chemist guessed that phosphorus was the root of the trouble and when a quantitative analysis showed this substance present in a large amount, the quest was at an end. The phosphorus, in combining with chromium, prevented it from alloying with the copper. In this way enough chromium was rendered inactive to prevent hardening of alloy "B." Remedy: cut down the phosphorus content of the alloy.

In another case, Wynne and his staff found their major clue to consist of one thousandth of an ounce of ash, hardly more than is flicked from a cigarette. But it was enough to effect a solution. Here the problem centered about the high arcback rate of a rectifier anode. Everything else was eliminated as the trouble-maker, until the search narrowed down to a pinch of incombustible ash in the bottom of a porcelain dish. An analysis of this residue showed that it was made up of some ten different elements, a number of which were present in amounts sufficient to cause the troublesome arcback.

Examples could be multiplied to include the story about the field engineer who couldn't explain flashovers on a pantograph trolley operating in his area. Less than one hundredth of an ounce of crusted deposit from a porcelain insulator was all that Wynne required to propose an answer to his problem. Or they could include the account of a routine, but highly important, analysis that showed how prolonged baking weakened the strength of fungicides added to insulating varnishes for protection of electrical equipment in the tropics.

Added up, these cases and countless others underline the key position that the analytical chemist plays on the team of science to solve industrial problems.

Use of Capacitors in Industrial Plants

Cost-conscious utilities and plants are chasing a hoary-old bugaboo these days—kilovars. The hunting gear is simple—capacitors and the know-how in their use. The results are eminently satisfying to plant-owning customer and utility alike.

R. E. MARBURY, *Manager, Capacitor Engineering Section, Westinghouse Electric Corporation*

THE desirability of shunt capacitors to correct power factor and improve voltage conditions in distribution circuits is no longer questioned. Instead the common question is how many and where to locate them. The decision as to amount of capacitors needed in a given case, their proper placement, switching, and even the exact objectives sought is based on several specific considerations, albeit fairly simple ones.

The magnitude of reactive current under conditions of power factor other than unity is often surprising. Even at 99 percent power factor the reactive kva flowing in a circuit is 14 percent of the kilowatts, as shown in table I. As the power factor drops to 70.7 percent the reactive kva is equal to the kilowatt load and the voltage drop per mile in a typical 4-kv feeder caused by reactive kva alone is nearly 4 percent. Also, supplying this parasitic or reactive kva overloads and produces considerable additional losses in lines, voltage regulators, transformers, and all equipment whose size is determined by total line current. Between generator and load, voltage is stepped up once and down at least three times. Low power factor results in additional loss in each transformation.

Effects of Power Factor

The load that can be handled by a power system is measured largely by current instead of real power. The load that can be delivered over lines, particularly those of 13 kv and less, is often determined by current-carrying capacity. But voltage, too, is important. Even when ability to carry current is not the limiting factor the power that can be transmitted is often determined by delivered voltage. If the load is of low power factor, such as 50 percent, the current flowing and the voltage drop are quite large, as indicated in table I. Even with a more common power factor of 70 percent the voltage drop due to reactive kva alone is double that caused by the kilowatt component.

Low voltage on a line has numerous bad effects. It causes incandescent lamps to burn low, fluorescent lamps to go out, and adversely affects motor characteristics. Torque and speed are reduced. In addition increased line current is required, which in turn reduces voltage still further, thus aggravating the condition, as Fig. 1 indicates. Too low a line voltage may trip the undervoltage relays in the motor controls and shut down operations. The voltage regulation of a transformer is also greatly affected by load power factor, as shown in Fig. 2.

Load Power Factors

Much can be accomplished in maintaining high power factor in the distribution circuit by selecting synchronous motors that operate at leading power factor. Use of these motors, however, is limited to certain types of loads. Where they do meet load requirements they provide a very economical means of maintaining high power factor. Even where only a few large motors in a plant are synchronous the overall power factor is often satisfactory.

Motors in many industrial plants operate at light load most of the time. Motor sizes are sometimes determined by peak load or starting-torque requirements rather than normal or average load conditions; the result is overmotoring.

Induction motors are generally the principal cause of low power factor, first because there are so many and second because of their inherent nature. While the power factor of induction motors at full load is usually quite high, 85 to 90 percent, the power factor under the actual operating conditions is more likely to be 60 or 70 percent most of the time. The power factor of a typical motor varies from 20 percent at no load to 90 percent at full load. The typical curve of Fig. 3 shows that a motor operating at quarter load draws from the line as much reactive kva as kilowatts.

Motor loads are not the sole cause of low power factor in industrial plants. Resistance welders are, in effect, transformers with highly reactive loads on the secondaries. A secondary is usually a short loop having a voltage that is low relative to the secondary inductance. The high secondary current produces a relatively large inductive drop, and this load viewed from the primary side appears as a load of 40 or 50 percent power factor. Transformer-type arc welders also have a low power factor because they are purposely built with a high internal reactance to limit current when the arc is struck. These welders often have in-built capacitors.

Induction furnaces in which the molten metal forms a short-circuited loop around a magnetic circuit have low power factor for the same reason as resistance welders. Electric-arc furnaces have low power factor because of in-built transformer reactance, similar to arc welders.

Power-Factor Correction in Industrial Plants

Shunt capacitors offer an attractive means of correcting power factor in an industrial plant because they can be spotted in small sizes at each particular load or concentrated in banks at power centers or at incoming feeders. This ability to locate the capacitor near the load or distribute it at many points on the system is one of the outstanding advantages of capacitors over synchronous condensers. The cost per kvar is not greatly affected by the size unless the total kvar is less then 45 for a three-phase bank.

Benefits of capacitors to the industrial power user are measured in two ways. First, in terms of saving on the power bill by taking advantage of rate structures created by the utility to encourage maintenance of high power factor. Raising the power factor of the entire plant load generally reduces the kva-demand charge, and in most cases the actual energy charge. Secondly, the user reduces kva load and losses in his transformers and feeders and maintains better voltage.

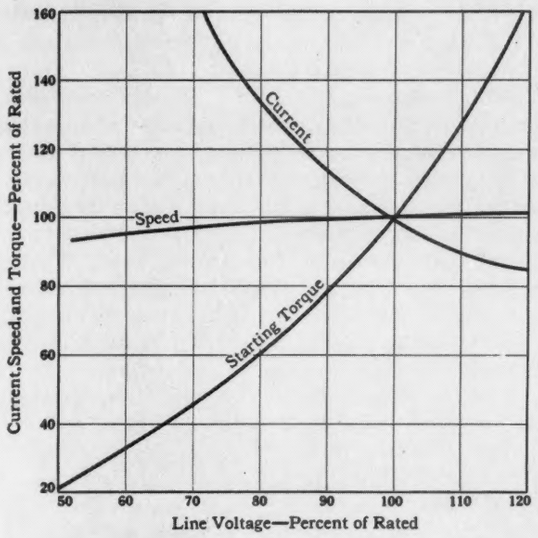


TABLE I—EFFECT OF POWER FACTOR ON CONDITIONS IN A TYPICAL FEEDER CIRCUIT

(3-Phase, 4-Kv, 4/0 Conductor, 33.6-inch Equivalent Spacing, Fixed 1000-Kw Load)

Load Power Factor	Reactive Kva in Percent of Kw	Percent Voltage Drop per Mile due to Active Kw	Effective Percent Voltage Drop per Mile due to Reactive Kva	Total Percent Voltage Drop per Mile	Total Line Current in Percent of Current at 100 Percent Power Factor
100	0	1.89	0	1.89	100
99	14	1.89	0.56	2.45	101
95	33	1.89	1.29	3.18	105
90	48	1.89	1.94	3.83	111
85	61	1.89	2.43	4.32	118
80	75	1.89	2.94	4.83	125
70.7	100	1.89	3.92	5.81	142
60	133	1.89	5.21	7.10	167
50	173	1.89	6.80	8.69	200

←

Fig. 1—Induction-motor characteristics are adversely affected by low line voltage. The high current required to drive a specified load further aggravates the voltage condition.

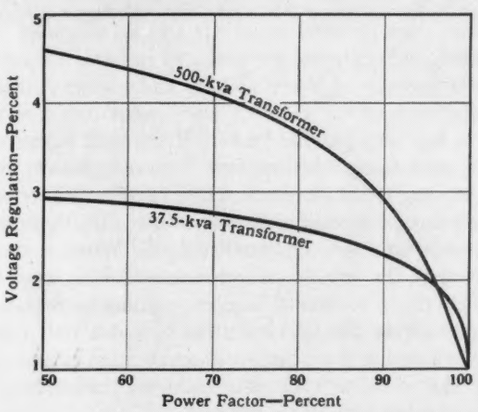


Fig. 2—Transformer voltage regulation, the drop from no load to full load, is greatly increased by low power factor.

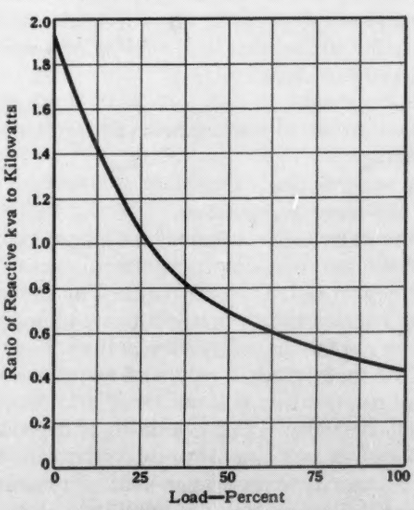


Fig. 3—While power-factor characteristics of induction motors are excellent at full load, the ratio of kvar drawn from the line to kw increases rapidly as load is reduced.

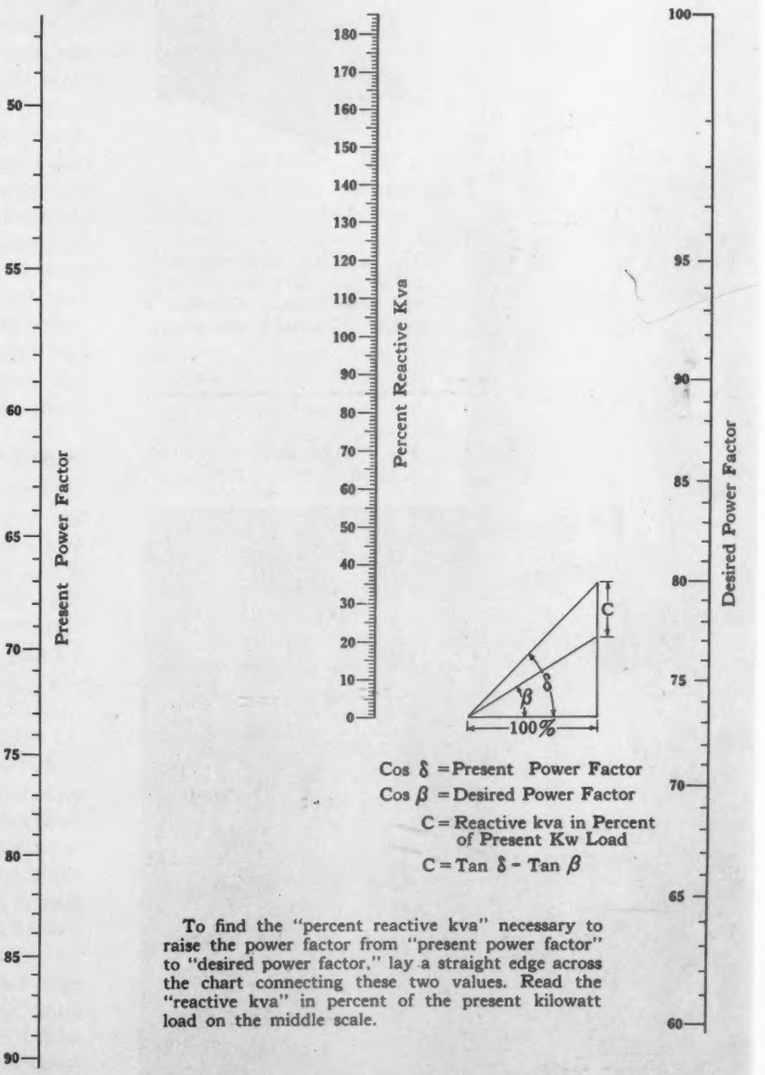

Present Power Factor
Percent Reactive Kva
Desired Power Factor
C
δ
β
100%
Cos δ = Present Power Factor
Cos β = Desired Power Factor
C = Reactive kva in Percent of Present Kw Load
C = Tan δ - Tan β
To find the "percent reactive kva" necessary to raise the power factor from "present power factor" to "desired power factor," lay a straight edge across the chart connecting these two values. Read the "reactive kva" in percent of the present kilowatt load on the middle scale.

Fig. 4—The amount of capacitors required to improve the power factor of a load is easily computed with the aid of this chart.

When the only consideration is power factor the application is simple. One need know only the load kilowatts and power factor and the power factor desired. The kvar rating of capacitors needed can be determined from a simple chart (Fig. 4) or by simple calculations.

The size of the capacitor that can be justified depends on the particular power rates and the manner in which credit is given for raising the power factor. These rates vary widely throughout the country but in general the saving returns the first cost of the capacitor in one to three years. In one steel plant, for example, a bank of capacitors totaling 2520 kvar paid for itself in power savings in eight months. In another plant, a smaller 50-kvar installation, the first cost was returned in two years. Both continue to yield a high return on the original investments.

If the analysis of plant conditions indicates that advantages can be gained by relieving transformers and lines of reactive kva or by improving voltage regulation, consideration should be given to placing the capacitors, instead of on the incoming line, on the load side of power transformers or even out on the feeders or directly at loads of low power factor. Whatever savings result from these special locations of the capacitor add to savings from the utility. These additional gains are made even if 230-volt capacitors are used but at some increased cost because 230-volt units generally cost more per kvar than those rated 460 volts or higher. Also the use of many small installations with additional switches may increase installation expense to some extent.

On the other hand, there are two beneficial effects cost-wise in placing capacitors out in the plant. One, switching equipment of lower cost may be usable. When the capacitor is placed directly on the primary a larger disconnect breaker of high interrupting capacity may be required to interrupt possible faults on lines between capacitor and transformer. On the other hand, fault currents are probably not as large on the plant circuits because of lower voltage and higher current-limiting impedance of the circuit. Two, capacitors directly connected to the load provide leading kvars that automatically change with load; when motors, for example, are idle, the corresponding capacitors are likewise idle. Therefore, placing a substantial portion of the capacitors directly on the load may result in a greater installed kvar. When a single bank is placed on the primary, automatic switching using an electrically operated breaker of high rating may be required.

The proper application of capacitors to industrial plants involves an evaluation of all these and many more factors. To this extent the selection and installation of the capacitors cannot be arrived at by any simple rule.

Fig. 5—This bracket-mounted 15-kvar, 460-volt capacitor is suited for direct connection to plant circuits and motors up to about 60 hp. →

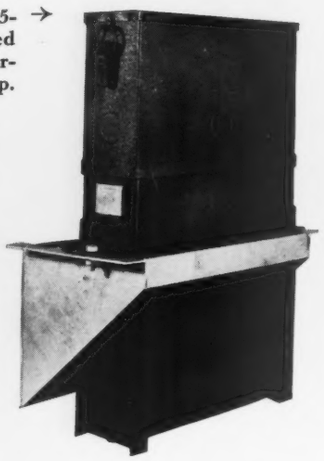


Fig. 6—This floor-mounted, 22½-kvar, 230-volt capacitor is connected through a switch directly to the motor.

Fig. 7—This bank of 460-volt capacitors totals 300 kvar.

Power-Factor Correction Viewed by the Utility

To the power company a capacitor is a kvar generator capable of supplying leading kva at desired points on a system. The addition of this reactive kva in an industrial plant is helpful to a utility for one or more of the following reasons:

a—Releasing generator capacity.
b—Reducing line current.
c—Reducing kva burden on transformers and regulators.
d—Boosting voltage.
e—Controlling or regulating voltage.
f—Extending the range of regulators.

The action of the capacitor in reducing load on generators, reducing line current, and releasing transformer capacity all comes about by the fact that the kvar required by the load is confined to the circuit existing between the load and the capacitor and never reaches the utility's feeder lines. The generators and lines are thus burdened only with real power and a small amount of reactive that it is not feasible to compensate by capacitors. The value of this to a utility is dependent on a large number of factors and of course varies considerably. The system capacity released per kvar of capacitors added decreases as the power factor is raised to values approaching unity, as illustrated by table II.

Where to Install Shunt Capacitors

Shunt capacitors can be connected directly to the terminals

Fig. 8—These high-voltage, indoor-type capacitor banks are rated 1260 kvar at 2400 volts.

of a motor and switched on and off with the motor by using a common control switch. In applying capacitors in this manner the capacitors should be no larger than required to supply the no-load reactive kva to the motor. Capacitors larger than this may cause self-excitation when the motor is disconnected from the line, resulting in the motor acting as an asynchronous generator, and require special consideration, especially for larger motors. This method of correcting motor power factor is desirable in that it provides capacitor kva that automatically changes as loads are switched on or off. However, the installation cost is generally higher because of the larger number of individual installations.

Shunt capacitors can also be directly connected to welders and switched with the welder. This is desirable only on welders where the duration of weld is quite long and the welder has an important effect on steady-state power factor of the plant load.

On spot welders, however, where the duration of weld time is short and instantaneous kva demand most important, it is better to use series capacitors. Since the duration of the weld is one or two cycles "on" and a few cycles "off" and the instantaneous demand is high, the transient is very important. Means of reducing it are a major consideration. A shunt capacitor cannot reduce instantaneous demand because it also draws a large inrush current, but it can diminish steady-state demand. However, a capacitor in series with the welder reduces the instantaneous kva demand to a value corresponding to the kilowatt demand.

The choice and location of capacitors in industrial plants are governed by load pattern, distribution of loads, shifting of load centers, and many other factors characteristic of a given plant. The reason for improving power factor may be one of power rates alone or may involve relieving of plant transformer or circuit overloads, maintenance of voltage, or a combination of several reasons. It is therefore desirable to set down all the reasons for improving power factor and enumerate the possible gains before attempting to decide where to place the capacitors or how many and what types.

Types of Capacitors

Capacitors are classified according to any one of many characteristics, such as voltage class, bracket or floor mounting, and whether for indoor or outdoor installation. One of the most common types for indoor industrial applications is the 3-phase, 15-kvar, 460-volt, Inerteen-impregnated capacitor enclosed in a dust-tight housing (Fig. 5). Each industrial Inerteen unit is protected by high-interrupting-capacity Deion fuses, which also provide maximum continuity of service.

Small or large banks of standard low-voltage industrial capacitors can be assembled to meet a wide variety of applications for power-factor correction of an individual motor or of a plant feeder. Typical installations of such assemblies are shown in Figs. 6 and 7.

For high-voltage plant circuits or incoming lines, larger assemblies of indoor-type capacitors are used. Enclosed in a standard housing (Figs. 8 and 9) they can be placed in indoor plant substations. Where outdoor installation is desired, weatherproof capacitors fill the requirements over a wide

TABLE II—EFFECT OF ADDING SHUNT CAPACITORS TO SYSTEMS OF DIFFERENT POWER FACTORS

Initial Power Factor	Kva of Capacitors Added per Kw of Load	Final Power Factor	System Capacity Released per Kw of Load	System Capacity Released per Kva of Capacitor Added
50	0.40	60	0.34	0.85
	0.72	70	0.58	0.80
	0.97	80	0.76	0.79
	1.25	90	0.89	0.71
	1.42	95	0.95	0.67
	1.72	100	1.00	0.58
60	0.33	70	0.24	0.73
	0.60	80	0.42	0.70
	0.85	90	0.56	0.65
	1.03	95	0.62	0.60
	1.33	100	0.67	0.50
70	0.28	80	0.18	0.63
	0.54	90	0.32	0.59
	0.71	95	0.37	0.52
	1.01	100	0.43	0.42

range of sizes. The banks of Figs. 10 and 11 are made up of such units. Indoor-type capacitors enclosed in weatherproof housings are also used for outdoor installations.

Automatic Control of Capacitors

The effectiveness of shunt capacitors can often be increased by switching a portion of the banks "on" or "off" as required. Either line voltage, total load current, or reactive load are used as the indicator. When using line voltage two things are accomplished: (1) Reactive kva is supplied as needed during peak load conditions without the risk of excessive voltage rise during light load conditions; (2) The voltage level of the system is regulated by applying the voltage boost when needed, as during conditions of heavy load.

If the system voltage is controlled by a regulator near the capacitor, voltage no longer serves as a reliable indicator of the need for reactive kva. Then either total load or reactive load are used. If the power factor remains relatively constant

Fig. 9—This enclosure will house a 2520-kvar, 13.8-kv capacitor bank. The cubicle at the right end is for a disconnect circuit breaker.

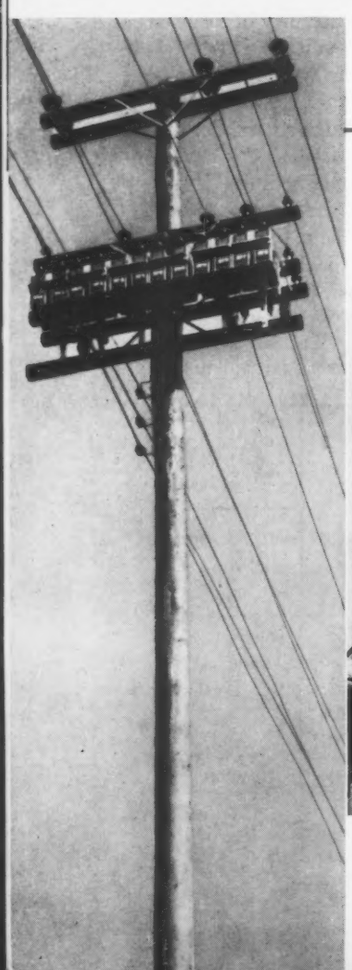
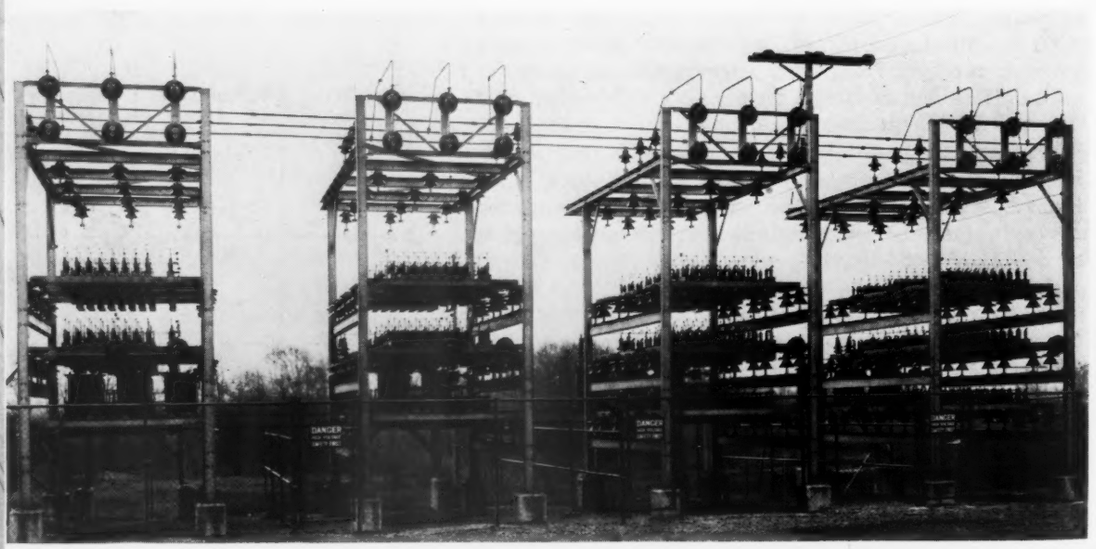


Fig. 10—This outdoor installation consists of twelve 15-kvar, outdoor, pole-type capacitors. Similar 25-kvar units are also available.

Fig. 11—Outdoor capacitors connected in series-parallel arrangement form this 10 000-kvar, 24-kv installation.



during wide variations in the load, switching can be controlled by load current because it is proportional to capacitor kvars required. If the power factor varies, it is then desirable to use reactive kva of the load to initiate switching operations.

Capacitor Rating and Operating Limits

Power capacitors are rated on the basis of kvars at the nominal rated voltage. Manufacturing tolerances are in the direction to give from rated kvar to 115 percent rated.

It is common practice to permit the circuit voltage to exceed the nameplate rating by a factor of 5 percent based on the average over any 24-hour period and by a factor of 10 percent for any period provided the 105 percent average is not exceeded. The kvars drawn by the capacitor increase as the square of voltage.

The voltage wave of any power system can be expected to contain some harmonics. Because the impedance of a capacitor decreases directly with frequency, a capacitor draws more than rated current when applied to a voltage wave containing one or more harmonic components. If the capacitor draws more current the operating kva is increased and its temperature is higher because the loss increases almost directly with kva, similarly to resistance load.

Standard capacitors are designed to operate satisfactorily up to 135 percent of rated kvar. The excess can be the result either of harmonics, or a combination of harmonics and overvoltage. If the capacitor is operating at the permitted 105 percent average voltage, the kvars are drawn about 110 percent rated. This leaves a 25-percent margin for harmonics.

When a capacitor draws more current than is to be expected from the measured voltage and more than can be explained by the manufacturing tolerance, harmonics can be suspected. The operating kva, however, cannot be determined simply from the measured voltage and current. The voltage or current must be examined by a harmonic analyzer and the predominating frequency determined. Frequencies other than the base and the dominating harmonic can usually be ignored. The operating kva of the capacitor can be determined by adding the calculated kva at the fundamental and the principal harmonic. This sum, however, should not exceed 135 percent of rated kvar.

The frequencies most likely to be encountered are 180 and 300 cycles, i.e., the third and fifth harmonics. Circuits rarely contain enough harmonics to produce appreciable currents in the capacitors at these frequencies unless the system reactance and capacitive reactance happen to be in resonance at the harmonic frequency, whereupon overloading of the capacitors or interference with telephone circuits may result.

Wave forms, however, are generally good and difficulties with harmonics are rare. Troubles such as do occur are easily dealt with so there is no appreciable problem in the application of capacitors due either to wave form or interference with telephonic transmission.

Standard, housed capacitors are designed to allow these variations in voltage and wave forms under ambient temperature of 40 degrees C. Unhoused capacitor units mounted openly are applicable within the same limits but allowable ambient temperatures are 50 degrees C.

Shunt Capacitors Versus Series Capacitors

Shunt capacitors connected in parallel with the load are used to supply reactive kva or to provide steady-state boosts in line voltage. A capacitor in series with an electrical circuit, however, effectively cancels inductive reactance in the circuit, thus improving voltage regulation due to fluctuating loads.

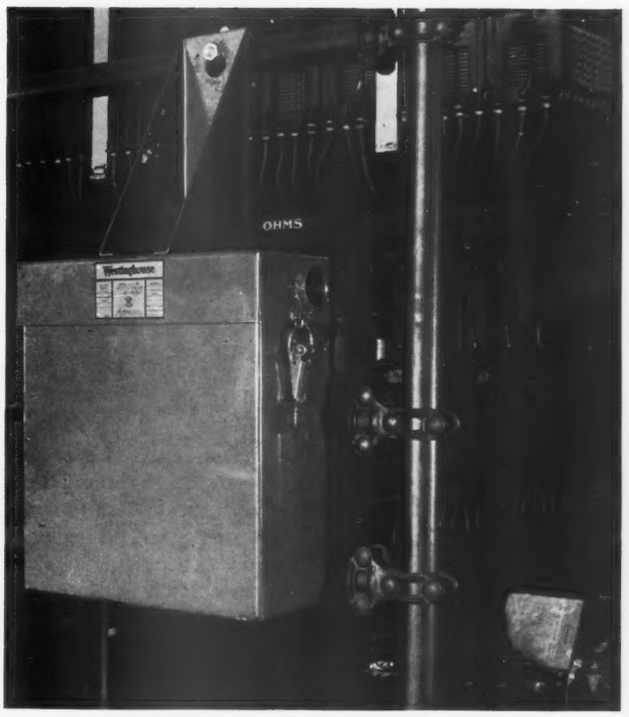


Fig. 12—Automatic control adjusts capacitance in a circuit as line voltage varies with load.

A series capacitor is particularly useful on circuits where lamp flicker is encountered because of rapid and repetitive load fluctuations such as caused by spot-welding machines or reversing motors. In many such cases voltage regulators are not sufficiently rapid to correct the voltage variations, but a series capacitor acts as an automatic voltage regulator with practically instantaneous response since, unlike the shunt capacitor, its effect increases with line current.

Even where lamp flicker is not present, a series capacitor can be used instead of a transformer-type regulator to improve voltage regulation on a circuit having a high reactive voltage drop. In general, the transformer-type regulator is less expensive, but the capacitor can be justified on long circuits, 2400 volts or above, which supply small amounts of power.

A shunt capacitor is used to correct power factor of the load. To complement this effect, a series capacitor is used to improve voltage regulation by compensating for the voltage drop caused by reactance in the line. Therefore, the improvement obtainable depends upon what portion of the voltage drop is caused by line reactance. A series capacitor will give a worthwhile improvement in voltage either when (a) the line reactance is equal to, or greater than, the line resistance; or (b) the load has a low power factor.

When a low power-factor load causes an excessive steady-state voltage drop, the condition should be corrected with a shunt, not a series capacitor. A shunt capacitor also causes a rise in voltage on the circuit to which it is connected. Shunt capacitors, switched in steps as needed, improve voltage regulation. Series capacitors should be considered only when a power-factor correction of the load does not give the desired results. The application of series capacitors by utilities to correct conditions on power lines to industry has been gradually increasing because of new equipment and techniques.

Krypton Lamp for All-Weather Landings

Man can seldom beat nature at her own game. But this he has accomplished. When dense daytime fog hugs the airport, even the sun, bright as it is, creates only a blinding haze. However, the new krypton lamp, tenfold brighter than the sun, is being used successfully to punch man-made strokes of lightning through such fog, giving to the pilot a positive visual indication of runway location.

G. A. FREEMAN, *Lamp Engineering Department, Westinghouse Electric Corporation*

CAPABLE of piercing a thousand feet of densest fog is the lightning-like brilliance of the war-born krypton lamp. Used in the All-Weather Approach Lighting* system to supplement radio or radar, a row of 36 krypton lamps, flashed one after the other 40 times a minute, provides the airplane pilot with an unmistakable visible indication of runway location and landing direction. While instruments can bring a plane close to the airport, the new lighting system gives the pilot the assurance possible only from direct evidence of his own eyes. The krypton lamp, whose surface brightness is ten million candlepower per square inch (the sun's is only one million), is combined with a large parabolic reflector that concentrates more than three billion candlepower in a narrow beam to obtain the required fog penetration. The new system promotes the possibility of landing airplanes in any weather.

*"Landing Airplanes in Any Weather," by W. A. Pennow, Westinghouse ENGINEER, July, 1947, p. 105.

Development of the Lamp

Tests conducted during the war indicated that light can penetrate adequate distances in dense fog provided extremely high candlepower is used. Flashing light was selected as the only means of obtaining the required intensity without blinding the pilot. In actual practice the duration of the flash must be short enough (only a few millionths of a second) that the eye will not even begin to respond to the great brightness and will not lose its dark sensitivity at night. The krypton lamp, whose flash lasts but 17 microseconds, meets this requirement.

In determining the proper design, commercial photographic flash lamps having long, coiled discharge tubing were considered first. Rapidly repeated flashing was found to shorten lamp life excessively unless very low energy per flash was used. But low flash energy results in very low efficiency. It was apparent, then, that a more compact and rugged flashing lamp, providing the maximum possible light intensity with

Fig. 1—Despite its small size, the brilliance of the krypton lamp makes the sun seem pale by comparison. In this parabolic reflector, it gives effective candlepower output of 3.3 billion. The lamp is shown above approximately four-fifths natural size. At left, the lamp and its reflector are tested.

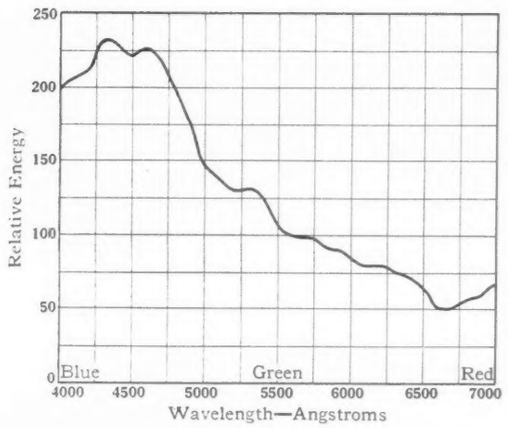


Fig. 2—Richness in the blue part of the spectrum gives the krypton lamp a blue-white appearance.

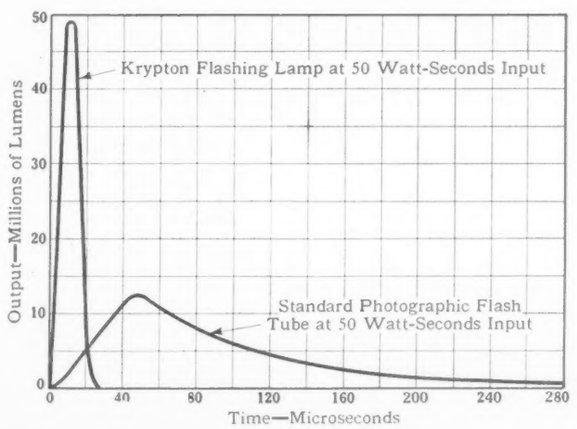


Fig. 3—Compared to a standard flash tube, the krypton lamp gives a higher output of shorter duration. The duration of flash is commonly taken as that above one third of peak.

repetitive flashing, was needed to fulfill the requirements.

A short, straight-tube lamp, using krypton gas, developed for experimental war projects was considered next. With its short arc length and relatively high gas pressure, the internal resistance during the flash is lower. Consequently, the krypton lamp gives a shorter duration of flash and for the same energy input a higher peak of light intensity is obtained than is possible with commercial photographic tubes. The krypton lamp uses high-melting-point fused quartz around the discharge space to better the extreme heat generated. However, the heat is so great that even the quartz surface softens and gradually vaporizes. Unless something is done about it the quartz recondenses to form a white powder deposit that obscures the light output.

The krypton flashing lamp finally developed uses fused quartz but with special provisions to collect the vaporized powder where light output will not be obscured. The central portion of the lamp is a thick-walled quartz tube two inches long with about one-fifth-inch inside diameter and two-fifths-inch outside diameter. At each end the low-thermal-expansion quartz is hermetically sealed to the high-thermal-expansion

TABLE I—CHARACTERISTICS OF KRYPTON LAMP

Peak output (million lumens)	49
Peak output—lamp only (million candlepower)	3.9
Effective peak output—with reflector (billion candlepower)	3.3
Surface brightness (million candlepower per square inch)	10
Effective duration of light flash—above one third of peak (microseconds)	17
Energy rating per flash at 40 flashes per minute (watt-seconds)	50
Rated life at 40 flashes per minute (hours)	25
Average rate of energy consumption during flash (kilovolts)	3000
Peak current during flash—estimated (amperes)	3000
Average power supplied to flashing lamp (watts)	33

metal terminals by means of a graded seal. The seals have a larger diameter than the quartz tube and form end cavities, which act as shock absorbers for the sudden expansion of gas during the flash. The vaporized quartz powder is blown into these cavities, leaving the quartz surfaces clean.

Lamp Operation

The lamp, known as type FLG-1, uses only 33 watts average power but the peak power in the flash is 3 million watts. It operates from energy accumulated in a 25-microfarad condenser charged to 2000 volts. Before ignition the lamp is nonconducting. Ignition is supplied by high voltage from an induction coil similar to that used in automobiles. When this voltage (about 25 000 volts) is supplied to the external wire surrounding the tube, electrostatic action between the wire and the main discharge electrodes ionizes the krypton gas causing its resistance to drop suddenly from practically infinity to less than one ohm (virtually a dead short circuit), discharging the condenser almost instantly.

The lamp has a rating of 50 watt-seconds per flash at 40 flashes per minute. Operated in this fashion, its rated life is 25 hours. Since the lamp is used only in the most severe fog conditions, and then but briefly (only when an airplane is landing), the life is spread out over many months of service.

The average rate of energy consumption during the flash, obtained by dividing the energy per flash by flash duration (measured at 17 microseconds), is found to be 3 million watts. The order of magnitude of the flash current is estimated using the formula for discharge of a condenser $T = RC$. Since C is 25 microfarads and T, 17 microseconds, R is 0.68 ohm. With 2000 volts applied to 0.68 ohm, the peak current estimated by Ohm's law is 2940, or approximately 3000 amperes. The average power required by the lamp (energy per flash divided by total time per cycle) is only 33 watts.

The candlepower of the lamp itself is slightly less than four million. The area of the light source is 0.4 square inches. Dividing candlepower by area, the brightness is just under 10 million candlepower per square inch. The magnifying effect of the reflector multiplies the light source almost a thousand times, projecting a beam of 3.3 billion candlepower.

Krypton gas in the lamp gives maximum light efficiency. Argon will give about 80 percent as much light and nitrogen still less. Krypton is a rare, expensive gas obtained by extraction from the air where it occurs only one part to a million. It is inert, classed along with helium, neon, argon, and xenon. Were it not for its high cost, krypton, because of its effect on luminous efficiency, would be used in place of argon in incandescent lamps.

Preliminary tests of the All-Weather Approach Lighting system have been in progress for several months at Cleveland Airport, the results of which have been most promising. The first complete installation is now being made in New York City's new Idlewild Airport.

A Telemeter Transmitter Without Moving Contacts

The operation of large power systems, sometimes covering thousands of square miles with many lines and scattered power sources, is dependent on continuous transmission of much information from remote locations to central points. Telemetering of power over long distances is vital. Now comes a new transmitter, simpler, with no mechanical operations. It is all electronic.

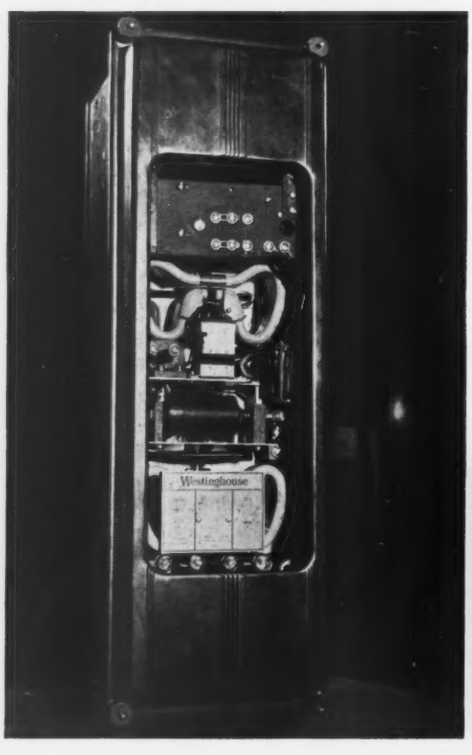
CARL OMAN, *Relay Engineer, Westinghouse Electric Corporation*

A NEW high-speed telemeter transmitter employs a weightless, frictionless light beam to provide the metering impulses. It consists simply of a light source, two rotating discs with holes, and a photoelectric tube and amplifier. Neither commutators nor rapidly operating, current-opening contactors are required.

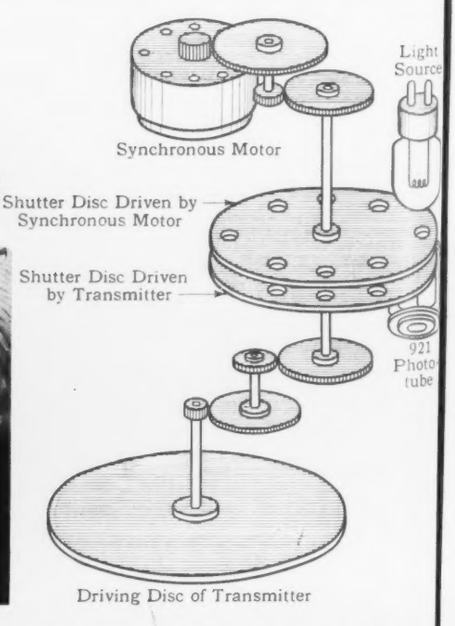
The electronic telemeter introduces no essential change in the system by which indications of electrical quantities, usually power, are transmitted from one point to another, frequently over long distances extending hundreds of miles. The telemeter transmitter produces continuously electric impulses at a rate proportional to the quantity being metered. These impulses are transmitted over a line, usually over pilot wires or by power-line carrier, to the distant point, which may be a dispatcher's office or load-control center. Here the impulses are reconverted to direct current proportional in magnitude to the rate of impulses and therefore to the initial quantity, and supplied to a direct reading or recording meter.

Heretofore the common method of generating the impulses has been by small commutator contactors whose rate of operation is a measure of the metered quantity. The impulses are sent into the channels by auxiliary relays, picked up by other relays, and there changed back to steady-load indications. The pulsing rate ranges from 40 per minute for the minimum quantity condition to 200 for the maximum. While this scheme is simple and has been employed extensively with success the continuous service imposes severe duty on contacts and relays, a relay often making a quarter million operations a day. It was the desire to eliminate these mechanical operations of circuit-opening contacts that led to the electronic scheme.

The measuring elements are fundamentally those of an induction watthour meter in which the discs of the moving element are driven at a speed in exact proportion to the load. Positive power turns the discs in one direction and negative power turns them in the reverse. Coordinated both mechanically and electrically with the meter are the impulse devices



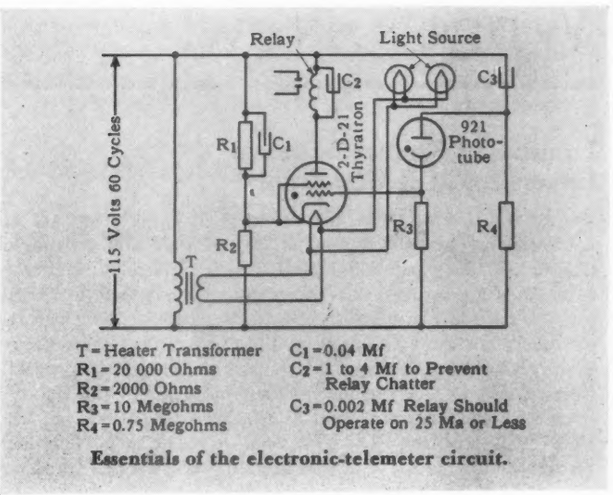
The photographs show the electronic telemeter close-up and on test by the author. The schematic drawing shows the two rotating discs, with identical holes. By the resulting rate at which the light falling on the phototube is interrupted, impulses are established that indicate quantity and direction of power flow at any point.



functioning in the following manner: At zero load the transmitter generates a constant, base impulse rate, but under other load conditions the rate is either increased or decreased from this base value, depending on the direction of power flow and by an amount proportional to the load.

These impulses are generated by means of a phototube and light source with two shutter discs having suitable holes for pulsing the light. The holes are of such size that the light and dark periods of an impulse are approximately equal. One shutter is driven continuously at constant speed, always in the same direction, by a synchronous motor. The other is driven by the measuring elements at a speed proportional to the load, and in either direction depending on the direction of power flow. The dimensions and spacing of the holes of the two shutters are identical. One shutter is mounted directly above the other, and the light must pass through the holes of both in order to strike the window of the phototube; hence, the rate of pulsing the light depends on the relative speed of the two shutters. At zero load only the constant-speed shutter turns, giving the base rate, but at other loads the second also turns, superimposing the load impulses on the base value. The arrangement of the shutters with respect to the light source and phototube is shown in the diagrammatic sketch.

The phototube conducts when light strikes its cathode, but the very small current must be amplified to operate other apparatus. Various forms of amplifiers can be used, but the circuit shown uses a 2–D–21 thyratron and 60-cycle control voltage. In this circuit the cathode of the phototube is connected to the control grid of the thyratron, causing it to fire at the same rate that the light is pulsed. The thyratron in turn operates a keying relay connected in its plate circuit. As this plate current is rectified half wave, a filter condenser is used across the relay coil to prevent chatter. The thyratron passes



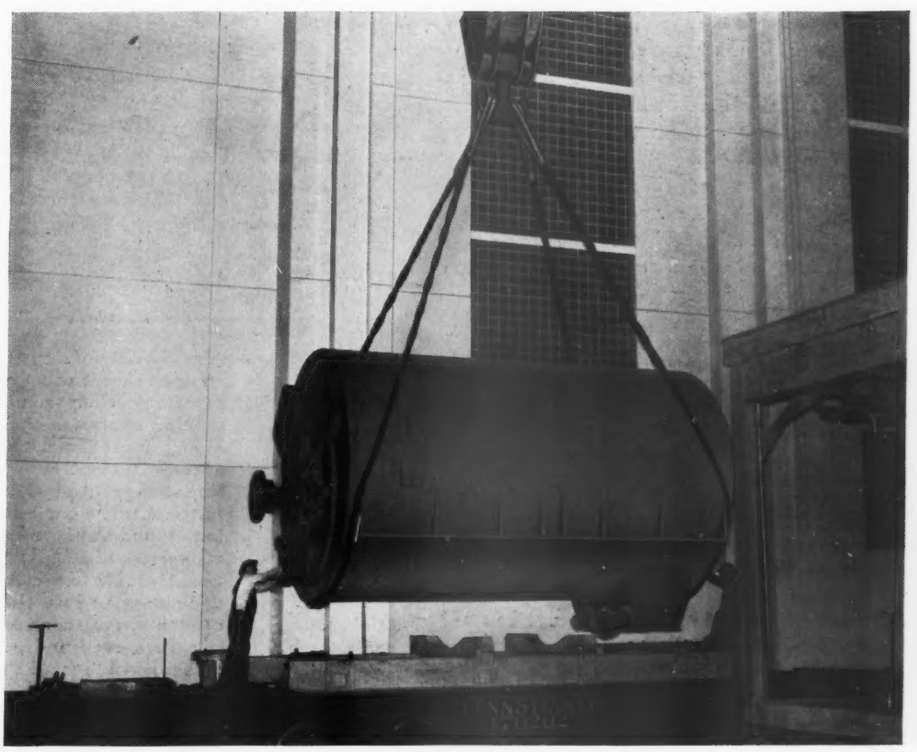
T = Heater Transformer
R1 = 20 000 Ohms
R2 = 2000 Ohms
R3 = 10 Megohms
R4 = 0.75 Megohms
C1 = 0.04 Mf
C2 = 1 to 4 Mf to Prevent Relay Chatter
C3 = 0.002 Mf Relay Should Operate on 25 Ma or Less

Essentials of the electronic-telemeter circuit.

current during the light period and none during the dark period of the pulse. When a thyratron fires, its grid loses control and cannot regain it unless the plate current is interrupted. For this reason a 60-cycle supply is used, the grid being able to regain control in the negative part of the 60-cycle wave when the plate current is attempting to reverse.

The operating range for transmitters of this design will usually be from 40 to 200 impulses per minute, 40 being the left end and 200 being the right end of the scale. These rates were selected because there is now in existence a large number of telemetering systems with commutator-type transmitters which have this range; hence, it is possible to rebuild old transmitters or add new ones without changing impulse rates.

Generator Shipped Completely Assembled



Being unloaded from a flatcar is this 60 000-kw, 3600-rpm generator, the first of its size to be shipped by Westinghouse completely assembled and with the rotor in place. The unit was built according to AIEE-ASME standards recently set up for turbine generators. The new construction features of standardized machines make it possible to ship generators in this fashion. The results are savings in shipping space (only one flatcar is needed) and in time required for loading, unloading, and final installation assembly.

What's New!

Laminated Frames Improve Reversing-Mill Generators

SOME improvements in the products of engineering are offspring of new developments in materials and techniques. Others hark back to fundamental theory and are stimulated by evidence of a growing need. An example is the case of d-c generators for reversing-mill service. Since the fields of the generators are reversed several times per minute to effect reversal of the roll motor, it has long been recognized that laminating the generator frame would do much to improve commutation of the high currents involved—currents that at times exceed 10 000 amperes. Yet, until recently, the additional expense and complexity accompanying the use of a laminated in place of a cast frame was not considered justifiable.

Now, increased steel demands, which require more reversals per minute and higher generator ratings, have stimulated the need for a simple laminated-frame machine. This has been fulfilled with expected gains of improved commutation and efficiency and reduced maintenance. Furthermore, it is possible that use of laminated frames will permit building generators to operate at higher speeds with an accompanying reduction in size.

Oscillographic tests to study the effect of laminating frames revealed that the speed of flux change is 50 000 times faster in laminations 0.0172 inch thick (approximately 27 gauge) than in solid steel. This is because laminations reduce eddy currents that oppose the reversal. In laminated-frame generators this same effect permits faster flux changes and consequently more rapid reversal of higher armature currents with better commutation. In many cases the advantages of laminated frames can be secured for existing generators merely by replacing the cast frame, a change that can be made during a week-end shutdown.

Commutation is much better with the laminated frame (above) than with the same reversing-mill generator using a solid cast frame (right).

Shockproof Midget Circuit Breaker

A NEW-BORN "baby" circuit breaker is destined to lead a hard life. It is capable of withstanding mechanical impacts of 500 foot-pounds without parts breaking or the bimetal vibrating and tripping open the circuit. The breaker is especially applicable to locations such as street transit systems, railway service, and marine applications, where space is at a premium and vibration is always present.

The breaker is actuated by a thermal bimetallic element that affords inverse-time-delay protection against overloads. Short-circuit protection is secured by a fast-acting mechanism. Contacts of special alloys and a De-ion arc extinguisher give an interrupting capacity of 5000 amperes and a current-carrying capacity up to 50 amperes at 125 volts alternating current. The breaker is adaptable for mounting on the back of the panel and is available with terminals for either front or rear connection. Mounting dimensions, exclusive of terminals and operating handle, are 3 inches long by 2⅛ inches deep by 1 inch wide.

A new family of a-c welders in ratings of 200 to 600 amperes has an open-circuit voltage of only 65 volts. The machines employ a capacitor-resistor arc-stabilizer circuit that provides improved arc-striking characteristics and arc stability with any type of a-c electrode at open-circuit voltages as low as 55 volts. The designed open-circuit voltage of 65 volts allows ample margin in case of low line voltage supplied to the primary of the welding transformer.

Accurate current settings are conveniently made by an adjusting handle and a uniformly calibrated current-indicating dial mounted together at the top of the welder. Welding current is controlled by a movable iron core that bypasses a different amount of flux, depending on its position, and consequently changes the circuit reactance. Thus current is changed without moving current-carrying parts, even under load. Use of grain-oriented Hipersil steel makes possible small lightweight units—only 440 pounds for the 400-ampere portable unit. The primary power factor of these machines is over 80 percent at rated current. Efficiency is over 90 percent from 20 percent to 125 percent load.

The bimetal is shock resistant and yet responds to a temperature rise caused by overload or short-circuit current in the conventional fashion. To combine all these desirable features in one, the bimetal was made in the form of an open "U," supported at a single point, and damped against vibration due to mechanical impact by a screw fixed in the breaker base. Thus, the bimetal is restrained from vibrating by the tripping latch on one side and the screw on the other. Normal overload action of the breaker occurs when the temperature rise due to excessive current expands the outer edge of the bimetal and reduces its radius. This deflects one side away from the latch, tripping the spring-loaded mechanism and opening the circuit. After tripping, the bimetal is allowed to cool for a period of approximately 45 seconds and the breaker is reset by moving the operating handle to the "off" position and then closed by moving to "on."

The U-shaped bimetallic element is restrained from vibrating by a tripping latch on one side and a fixed screw on the other.

A Better Transformer Safety Valve

POWER transformers generally have a safety valve or pressure-relief device that limits the rise in tank pressure should trouble develop internally that the normal protective measures do not prevent. Such devices, while they operate rarely—sometimes never in the life of a transformer—are important in that they may spare a transformer tank major damage.

Relief devices have previously consisted of a diaphragm of glass, Micarta, or metal that breaks to relieve pressure. But even the best do not always rupture at the calculated pressure. Also, they are subject to variations depending on minute manufacturing differences and, particularly, on the rate of pressure rise. A new mechanical-trip safety valve has nothing to break or rupture. The pressure at which a relief device operates can now be preset accurately to any desired value within a broad range. After operating, it is simply reset without the need for new parts.

There are other advantages. The valve will withstand a full vacuum, can be locked to permit pressure testing of the transformer tank, and has no parts to break during shipment. Transformers can be shipped from the factory filled with oil or nitrogen under pressure with the relief device installed.

A sylphon bellows arrangement is the key to its operation. The pressure on the bellows operates a roller trigger latch that permits the cover plate to fly open. Until this happens there is no movement of parts. Mechanical relief devices are now standard on power transformers and can be applied to existing installations.

Better Sterilamps for Germicidal Battles

SHOULD an "all-out" war be declared against those harbingers of disease and waste, bacteria, weapons in the form of two new Sterilamps are at hand. The lamps bring new efficiency to the science of germ killing.

The first is a 25-watt Slimline lamp 36 inches long that not only generates and transmits more germ-killing "bullets" per watt input but also provides a higher, more constant intensity over a longer period of life. The improvement, as might be suspected, is the result of several developments, not just one. For one thing, the Sterilamp utilizes a new-type, cold-hot electrode that operates cold for high-voltage instant starting and hot for efficient, continuous operation. At 200 milliamperes lamp current, the ultraviolet bactericidal output is more than double that previously available. A unique feature is that the ultraviolet output can be varied by changing the standard Slimline fluorescent lamp ballast to draw either 100, 200, or 300 milliamperes.

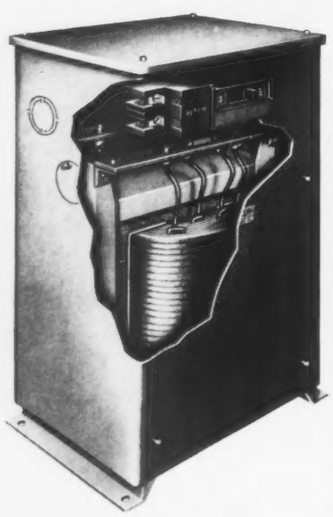
A second development is a new glass that has far better ultraviolet transmission characteristics than heretofore used. The new glass not only initially passes roughly fifty percent more of the germ-killing radiation (2537 Angstroms) but also—and this is especially important—the transmission is maintained relatively constant (the minimum is about 85 percent of initial strength) during the entire life. This constant intensity is due to a new glass that has a remarkable resistance to solarization, an opaquing effect that rapidly diminished the ultraviolet potency of former lamps. Actually the glass closely approaches fused quartz as to ultraviolet transmission but without its high cost.

The mechanical relief valve is easily installed on a transformer.

This Sterilamp installation protects food in a processing warehouse.

The rated life at 12 hours per start is 6000 hours, 50 percent more than previous similar lamps. The relatively constant intensity of radiation throughout its life has two distinct advantages. First, the waste from excessive and unnecessary radiations during the early part of the lamp's life is minimized; and second, the danger of insufficient radiation as the lamp approaches the end of its life is reduced. The high intensity makes the lamp suitable for applications that require a large amount of ultraviolet but where space limits the number of lamps to be used. It is also applicable to air conditioning, food-conveyor lines, water treatment, to other commercial installations, and to schoolrooms. The quantity of ozone produced is negligible because the new glass restricts the 1850-A ozone-producing radiations, yet without loss of the 2537-A line, a loss that had been as high as 25 percent.

Dry-Type Transformer



Dry-type transformers, now with built-in primary circuit breakers, provide single-phase 60-cycle power with thermal overload protection and a disconnect means for lighting and other industrial purposes. Complete in themselves, the transformers can be directly wired to open, flexible, or rigid conduit and eliminate the necessity of junction boxes, primary switches, or circuit breakers required by previous units. The circuit-breaker handle projects through the transformer case. The thermal trip units permit temporary overloads but prevent damage by short circuits. Ratings are 3 to 50 kva at 240 to 600 volts primary and 120/240 secondary.

The second new Sterilamp is a 16-watt cold-cathode instant-starting unit that produces about 45 percent of the intensity of the 25-watt. This lamp is remarkable in that it permits control of the amount of ozone produced in an irradiated area. The rated life of 9000 hours is independent of the number of starts.

The lamp is made in two types, both constant intensity. The first restricts the transmission of the 1850-A wavelength and produces little ozone. The second, using a slightly different glass, generates a high concentration of ozone, useful for killing bacteria in shaded areas. Thus, it is possible, for the first time, to apply bactericidal lamps to obtain the proper amount of ozone concentration for any application. The low-ozone lamp is for use in peopled areas, such as schools, offices, and homes. The high-ozone lamp is for product protection, as in food warehouses. Combinations provide a flexibility that fulfills any requirement.

Airport Runways Unmistakably Outlined

A BETTER light source for marking the outlines of airport runways and taxi strips has appeared. The problem is to provide a unit that gives an indication by light but without itself being a hazard. The solution has been, and still is for many installations, to use a contact light, consisting of a lamp and reflector system of which all but about three inches is below ground, the light emerging between ribs of the above-ground portion as a flat beam along the runway. This unit achieves a high degree of safety, as it can be run over by a plane without harm. However, even with the most powerful lamp possible and the most efficient lens system, the light output is limited. At times of poor visibility—in fact when it is most needed—the light is just plain inadequate.

The new unit embodies a different approach to the problem. Instead of burying it in the ground, which makes high light output impossible, it is mounted above ground on a stem with a purposely weak element so that if struck it bounces out of the way with little harm, if any, to the plane. With the unit in this position engineers could really go to work on light output. They provided not one light source but three and arranged them so the light output varied over a range of 6000 to one to meet every visibility condition. This feature is most important, as on clear nights mere points of light are sufficient. The minimum brightness of 16 candlepower is ample; more would cause glare. When fog settles in, either by day or night, an output of 100 000 candlepower is required to punch through the murk. This is 100 times more than is available from the "button" type contact light. Between these extremes of light output are eight other steps, from which the control operator can choose as conditions dictate.

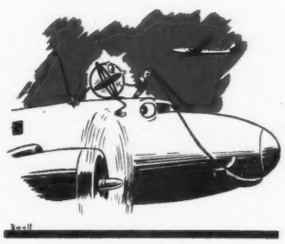
This marker provides an indication of airport runways over a range of conditions.

Low intensities are provided by a lamp and refractor perched on top the main, horizontal barrel-shaped element. This provides points of light visible in all directions, as is desired when air is clear. For fog conditions, within each end of the central element is a powerful sealed-beam lamp to direct a strong beam along the ground, outlining the landing zone—as is most important when the air is full of light-absorbing vapor.

This unit is considered to be a long step forward in solving the tough problem of plane-landing safety. It is being applied extensively in the United States and at some 150 fields in Turkey, China, South Africa, Venezuela, and other lands.

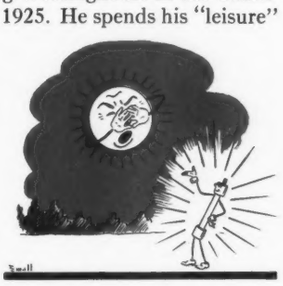
Personality Profiles

K. A. Oplinger's work with gyro controls and regulators has carried him all the way from the laboratory to a "front seat" in the gun turret of a B-25. Life is a little less hectic for him now, though nonetheless productive of new ideas, notably peacetime applications of gyro achievements during the war.



He came to the Research Laboratories in 1928 to join C. R. Hanna, designer of the tank-gun stabilizer and a fellow graduate of Purdue University, which awarded Oplinger a B.S. in E.E. in 1922. His first work was on recorders for talking-picture equipment and he helped develop a portable type for the fast-growing newsreel outfits of those days. After that he moved into the regulator field and was in on the early development of such notable devices as the Silverstat. During the war he helped produce the antenna positioner for the SCR-270 radar set of Pearl Harbor fame and assisted in the development of the voltage regulator used by the Army as standard equipment in its bombers. His pet project was probably the gun-turret stabilizer that Westinghouse designed for the Army's bombers. There are no laboratory tests, he admits, to compare with the experience of sitting in a B-25 bomber as it fires a 50-caliber barrage at targets towed by darting and twisting fighter planes. Recently he has had much to do with the research behind a new gyroscopic automatic pilot as well as the actual flight testing of early models.

A native of Taylorville, Illinois, Oplinger taught three years at Purdue before joining Westinghouse in the Transformer Division at Sharon in 1925. He spends his "leisure" hours amusing a pair of exuberant youngsters. Sometimes wishes he could develop a means of regulating their speed, position, and power output.



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The experience of *G. A. Freeman* in the lamp business essentially has spanned the whole development of vapor-discharge light sources. And he has been in on nearly every phase of it. First, after joining the Westinghouse Lamp Company in 1933, upon graduating from Brown University (B. S. in E. E.), he was occupied with development of the coiled-coil filament lamp, obtaining a patent on one phase of the development. But in 1935 he began active work on the then new mercury-vapor lamps. He helped devise the 250-watt and 400-watt mercury lamps, still standard. This was given an impressive and spectacular public debut as light sources for illumination of the lawns and Perisphere at the New York World's Fair. Quite possibly your artificial suntan may have had an assist from Freeman. He had a large part in the evolution of the RS sunlamp and helped convert a war plant to its large-scale manufacture. His special forte was the development of suitable seals, from which has stemmed his association with various types of flash tubes, the circular fluorescent lamp, and the Sterilamp. He is assisting now generally with new lamp development. If this activity were to leave him any free time, he would go skiing—if there were any snow.

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Capacitors for power-factor correction are one fifteenth as large as they were 25 years ago when *R. E. Marbury*, just out of Georgia School of Technology, first started working with them. And he has had a major part in nearly all the steps of that reduction. He was on hand at Westinghouse in 1918 when the trial installation of capacitors was made, and helped establish their commercial production in 1924. At that time capacitors were applicable only for voltages of 2300 and above because of their high cost. Marbury was largely responsible for the first low-cost 230- and 440-volt units that came out in 1925. In 1934, when capacitors had attained such stature as to warrant setting up a separate section, the logical choice for its manager was Marbury. He was in charge of the development that led to the Westinghouse fireproof, synthetic-impregnated capacitor in 1934 and to the first capacitor suitable for outdoor installation, in 1937. He has, needless to say, been in charge of capacitor engineering at Westinghouse for many years. Much of his effort has been spent in capacitor application, which has included the solving of a wide variety of central-station and industrial problems. When the need for a good textbook on power capacitors became evident recently to a large publisher, Marbury was asked to do the writing. This book is his current hobby.

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Those readers of the *Westinghouse* ENGINEER who were fans of *The Electric Journal* know *Carl Oman*. He probably answered more questions in the "Question Box" section in that publication than any other engineer. The number of problems on relays, instruments, and meters doubtless ran into the hundreds. Oman has been specializing in these devices for the past thirty years. Not always, however, has he worked with such "little stuff." He fondly recalls that soon after leaving the University of Kansas, with a B.S. in E.E., (1916) he helped test the huge motors for the "Tennessee," the first battleship to be electrified. Oman employs his spare time in a farsighted manner—he is an amateur astronomer and telescope builder. In fact, the telescope mounting he designed and built for his own instrument earned mention some years back in the *Scientific American* magazine.

Reproduction

This a-c welder is joining halves of the frame ring to produce other a-c welders, in this case for a unit of the "65-line."